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FOREST *Science*

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The cover design is a reproduction of a steel engraving by Charles Edward Faxon in Sargent's *Silva of North America, 1890-1902.*

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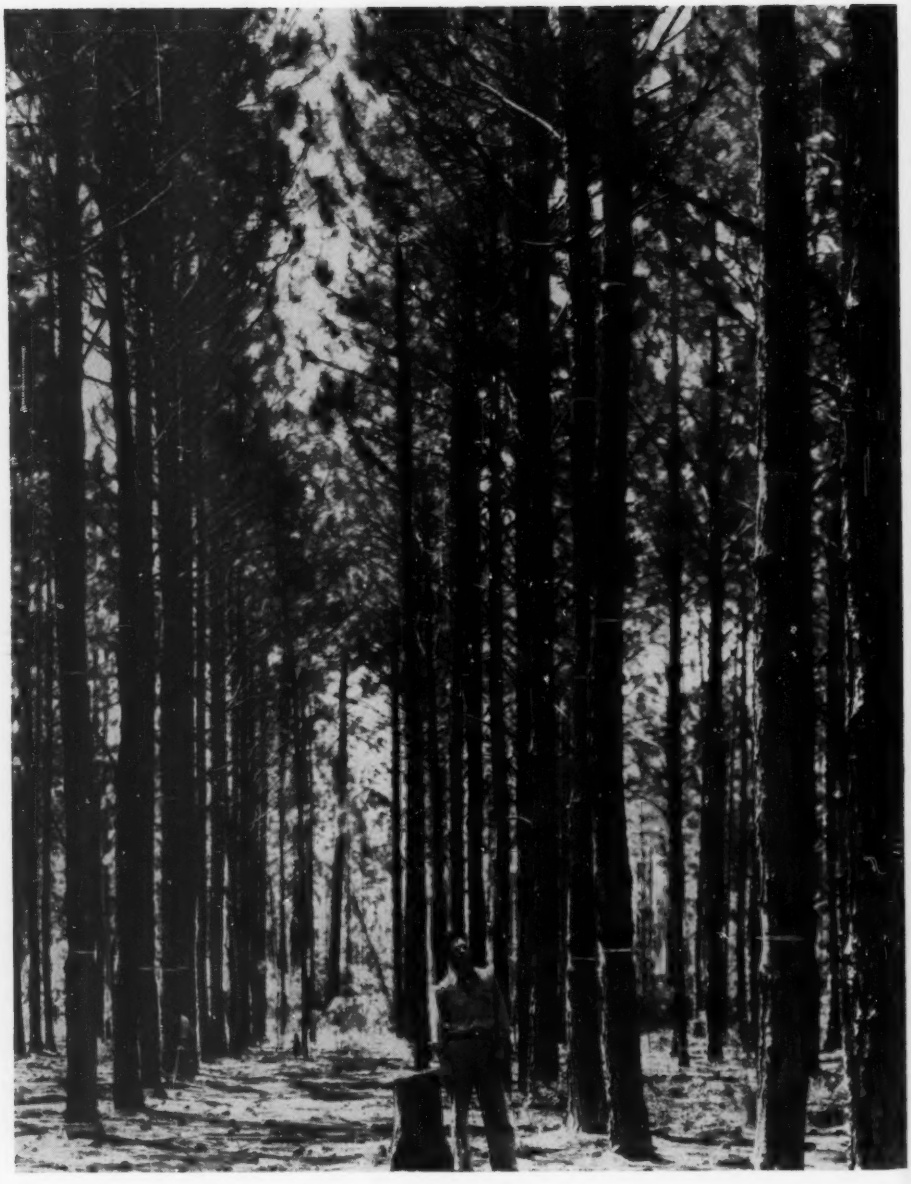

FIGURE 1. Vernier growth bands installed on slash pine trees in a 20-year-old plantation.

Effects of Turpentining on Growth of Slash Pine: First-Year Results

BY

C. S. SCHOPMEYER

ALTHOUGH some information is available on the effect of turpentining on pine growth (Cary, 1928; Harper, 1937; Oudin, 1938; Crivellari, 1949; de Phillipis, 1949) more facts are needed on the subject, especially on the effect of turpentining by the newer methods of bark chipping and chemical stimulation (Ostrom, 1945; Snow, 1949). Therefore, in the spring of 1953 experiments were initiated to determine (1) the amount of reduction of growth in pines turpentined by several methods, and (2) whether the reduction in growth is a consequence of severing part of the phloem and cambium, the amount of oleoresin extracted, or both. Results obtained during the first season are reported here. The study is being continued.

A plantation of 20-year-old slash pine (*Pinus elliottii* Engelm.), spaced 15 by 15 feet, was made available by the National Turpentine and Pulpwood Corporation. In this plantation, located in Baker County, Florida, 125 trees between 10 and 11 inches d.b.h.o.b. were selected for the study.

To measure tree growth, vernier growth bands (Hall, 1944) were installed on the bole, 5, 13, and 21 feet above the ground (Figs. 1 and 2). Measurements on these bands permit computations of volume in the 16-foot log above the turpentine face.

Bands were made according to the general specifications given by Hall, but some modifications were necessary because the materials specified were not readily available. Bands were cut from sheet aluminum 0.012 inch thick and half hard. The springs used to hold the bands in place were $\frac{3}{16}$ inch in diameter and 2¼ inches long. They were made from wire 0.013 inch in diameter. The tension provided by these springs was not great enough to take all of the slack out of the band; so bands had to be pulled tight by hand when read. A wire diameter of 0.016 inch would have been better, but springs with this size wire were not available in the quantity needed. A tab for attaching the spring to the band was riveted to each band with a copper tape-mending rivet. Bands were cut to predetermined measurements for each position on each tree. The scale and vernier were inscribed with the aid of a template and stylus provided by Dr. P. J. Kramer of Duke University.

In preparing the trees for band installation, bark was shaved and sanded at three places on the bole — 5, 13, and 21 feet above the ground.

The 125 banded trees were divided into 5 groups of 25 trees each, arranged in randomized block design. The groups were treated as follows:

A. Check. — round trees (not turpentined).

B. Bark chipping with streaks ¾ inch high made biweekly and sprayed

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with a 50-percent solution of sulfuric acid.

C. Same as *B*, but with the face split up into five small segments equally spaced around the circumference of the tree.

D. Same as *C*, but with the width of each of the five small faces about half that of *C*.

E. Wood chipping with streaks ½ inch deep radially and ⅜ inch high made weekly.

Gum yields from each turpentined tree were weighed monthly during the first season of work.

Amount of Growth Reduction

Analyses of variance of the initial measurements of circumference before treatment revealed no significant differences either between blocks or between treatment groups, for any of the three levels on the bole at which measurements were made. Hence any differences in volume detected after treatment can be attributed solely to treatment and not to initial differences.

Volume growth and gum yields during the period March 19 - November 25, 1953, are listed in Table 1.

The rate of deceleration of growth was more rapid in turpentined trees than in round trees during the first growing season. This point is shown in Figure 3 and in the following tabulation:

Period — 1953	Volume growth of turpentined trees expressed as percent of round (check) trees
March 19 - May 18	90
May 19 - July 20	76
July 21 - Sept. 21	56
Sept. 22 - Nov. 25	45
March 19 - Nov. 25	76

Nothing in the older work on this subject has shown such a difference in rate of deceleration, but continuation of the measurements during the second year of work will reveal whether or not this trend continues.

The mean reduction in growth for the two conventional turpentining treatments, B and E, was 26 percent (Table 1). This reduction checks closely with the 27-percent reduction for one face on a tree reported by Harper in 1937. Harper also reported 40 percent reduction for two faces (streaks cut ½ inch deep radially and ½ inch high at weekly intervals).

Analysis of variance of growth measurements showed that the reduction was highly significant for all turpentining treatments when compared with the unturpentined check trees, but there were no significant differences in growth between the four turpining treatments. Hence, the reduction in growth resulting from bark chipping and acid treatment of streaks is either no less than that obtained with shallow wood chipping with nailed gutters or so small that its significance at the end of the first season could not be established.

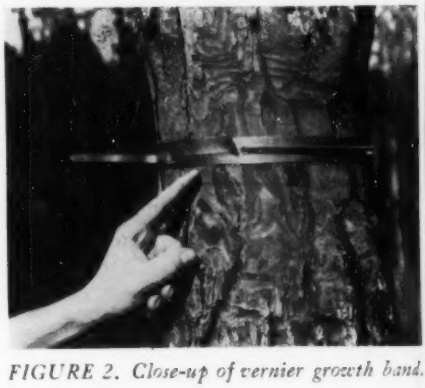

FIGURE 2. Close-up of vernier growth band.

Cause of Growth Reduction

To determine whether growth reduction is caused by the wound itself, the amount of oleoresin extracted from the tree, or both, a multiple regression was set up for the data obtained. Since oleoresin yields and growth during turpentining are each affected by the volume of the tree at the time gum extraction is started (Schopmeyer and Larson, 1955), initial volume was included as a variable in the analysis.

TABLE 1. Mean volume increments of onet 16-foot log and mean gum yields per tree for the period March 19 to November 25, 1953.

Code	Turpentining method: Streak type	Treatment	No. of faces	Face width	Total effective face width[1]	Volume increment		Gum yields: Total	Gum yields: Per inch of effective face width
				Inches	*Inches*	*Cu. ft.*	*Percent*	*Pounds*	*Pounds*
A (check)	None	None	0	.0	.0	.302	100	----	----
B	Bark	Acid	1	10.0	11.0	.217	72	9.34	0.849
C	Bark	Acid	5	1.5	12.5	.214	71	10.95	0.876
D	Bark	Acid	5	0.5	7.5	.243	80	7.29	0.972
E	Wood	None	1	10.0	10.0	.230	76	9.96	0.996

[1]Corrected for ½-inch lateral penetration of acid on each side of each face.

The variables were as follows:

log $10Y$ where Y = growth in cu. ft. during the 1953 growing season

X_1 = initial volume of one log in cu. ft. on March 19, 1953.

X_2 = gum yield in pounds per inch of wound width during the 1953 growing season.

X_3 = (intact circumference in inches)^2 = (circumference at 5-ft. level minus wound width)^2

Gum yields were computed for unit width of wound to eliminate the effect of the different wound widths in the four treatments. This measure of oleoresin yield is an index of the yield capacity of the tree and is thus independent of wound width or intact circumference, but not necessarily independent of initial volume. Empirical trials of plotted means revealed that the relationship between growth and intact circumference was curvilinear and that the log of $10Y$ and the square of the intact circumference, X_3, were suitable transformations for obtaining a linear relationship.

Tests of significance with 96 degrees of freedom revealed that only the coefficient for X_1 was significant. The lack of correlation between X_2 and Y indicates that, after the effect of initial volume was accounted for, the amount of oleoresin extracted from the tree had no demonstrated effect on growth. The sample of 100 trees was large, and the range in both gum yields and growth was wide, the highest values of each having been about 4 times the lowest. So the sample probably was adequate for detecting any significant correlation between gum yield and growth which might have been present after the effect of initial volume was isolated.

The lack of a significant regression coefficient for X_2 in this sample might be attributable to the small range of wound widths in the four treatments (Table 1) and to the fact that a constant correction for the lateral penetration of the acid sprayed on the wounds was used instead of individual measurements on each tree. Because measurements cannot be made without increasing the wound width, they will not be made until gum extraction has been completed. Hence, this regression may not have been an adequate test of the correlation between intact circumference and growth within treatments.

Inclusion of the data on the check trees provided a much wider range for the measurements of intact circumference. Therefore, a second regression was made on all five treatment groups using only X_1 and X_3 as the independent variables. The equation, computed from the individual observations on 125 trees, is:

$$(\log 10Y) = -0.100816 + 0.0551345X_1 + 0.000262325X_3$$

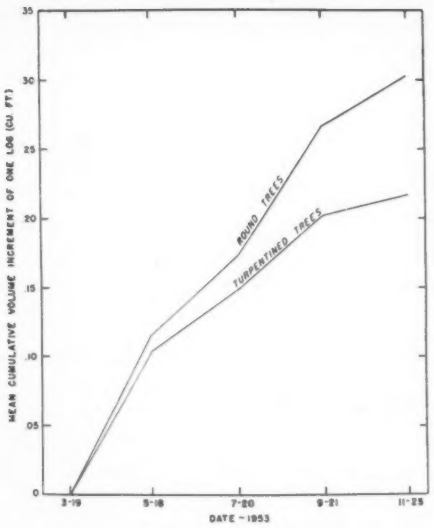

FIGURE 3. Bimonthly growth increments of turpentined and unturpentined trees during the first year of turpentining showing an accelerated rate of reduction resulting from turpentining as the growing season progressed.

The coefficient for X_1 is significant at the 1.0-percent level and the coefficient for X_3 is significant at the 0.1-percent level. The significance of the coefficient for X_3, however, is primarily the result of the difference in growth between the check trees and the turpentined trees, because this coefficient was not significant in the previous regression where only the turpenined trees were included. The second regression equation accounted for 24 percent of the variation in the logarithmic transformation of growth.

To demonstrate this correlation graphically, a regression was computed on the adjusted means for each of the four treatments and for the check. First the mean growth increments (Y) were adjusted for differences in initial volume (X_1), using the following equation derived from the regression of growth on initial volume within all five groups (four treatments and one check):

$$\text{Adjusted } Y = Y - 0.03922\ (\overline{X}_1 - \overline{\overline{X}}_1)$$

In this equation $\overline{X}_1$ is a treatment mean and $\overline{\overline{X}}_1$ is the mean of all treatments. Then the regression equation was computed as follows:

$$\log\ (10 \text{ adjusted } Y') = 0.25448 + .00028128\ X_3$$

This equation accounted for 99.94 percent of the variation in the transformed mean growth increments.

The very slight deviations of the actual values of the transformed means from the regression values are shown in Figure 4.

This regression is convincing evidence that the growth of trees during turpentining is a function of wound width. Since face height was constant, the effect of face height could not be evaluated.

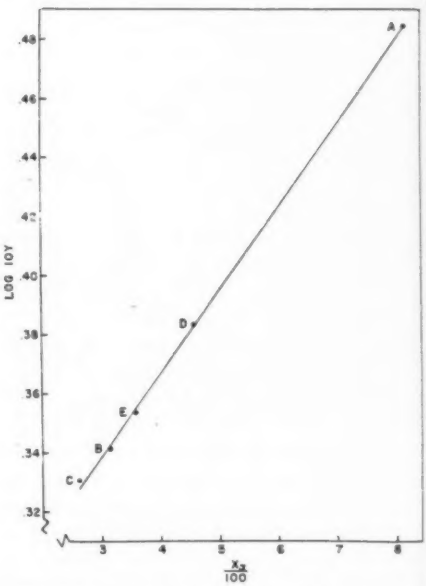

FIGURE 4. Deviations from the regression equation:
log 10Y = 0.25448 + 0.00028128 X_3, where Y = mean growth increment for treatments adjusted for differences in initial volume (cu. ft.), X_3 = [initial circumference minus face width (inches)]²
Letters indicate treatments and check as listed in Table 1.

Summary

Volume growth of a 16-foot section of bole between 5 and 21 feet above the ground was measured, using vernier growth bands at three heights on five groups of 25 slash pine trees each. The trees were growing in a 20-year-old plantation in northern Florida. The treatments included four different methods of turpentining. One group of trees, the check, was unturpentined.

Data for the first growing season showed a reduction of 26 percent in growth for the two conventional methods of turpentining. No significant difference in growth was detected between trees with wood-chipped streaks and trees with bark-chipped, acid-treated streaks or between single faces and small multiple faces. The rate of deceleration of growth was more rapid in turpentined trees than in round faces.

After correction for differences in initial volume the mean growth for each of the four treatments and the check showed high correlation with the intact circumference (circumference minus wound width). Conversely, the reduction in growth caused by turpentining is a function of wound width. Yields of oleoresin, however, were not correlated with concurrent growth.

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The Uncommon Denominator in Photosynthesis as Related to Tolerance[1]

BY

JOHN P. DECKER

THE appearance of a recent article by Verduin (1953) serves to reemphasize the fact that expressing photosynthesis on a unit leaf area or weight basis has become a widely accepted practice among plant physiologists. More caution is required than has been exercised in the past in interpreting the ecological significance of such data.

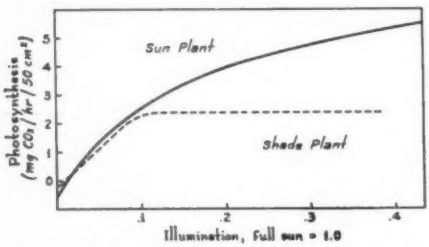

FIGURE 1. The relation of photosynthesis to illumination for a sun plant (nasturtium) and a shade plant (oxalis). Photosynthesis is expressed as rate/unit leaf. Redrawn from Lundgårdh (1931: Fig. 8).

The classic example is that of Lundegårdh (1931). He interpreted his Figure 8 (redrawn here as Figure 1) as showing that "At weak light intensities the assimilation of shade leaves is as efficient as that of sun leaves or perhaps even more so. But above a certain light intensity the behavior of sun and shade leaves begins to diverge (Fig. 8), a phenomenon of obvious ecological significance." His data were expressed in terms of unit leaf area. His interpretation was based on a direct comparison of the heights of the curves and thus requires the assumption that a unit of oxalis leaf has exactly the same "ecological" value to an oxalis plant that a unit of nasturtium leaf has to a nasturtium plant. This assumption can be stated more exactly: the total amount of photosynthesis required for a given degree of plant behavior divided by the total leaf area yields a value which is constant irrespective of species. The present writer knows of no evidence to support the assumption.

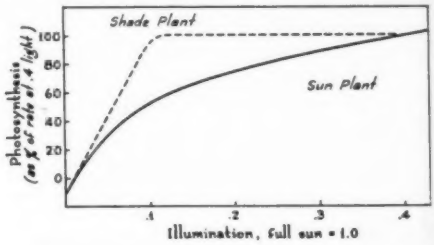

FIGURE 2. The relation of photosynthesis to illumination for a sun plant and a shade plant. Photosynthesis is expressed as the percentage of the rate at 40 percent of full sunlight. Recalculated from Fig. 1.

[1]The meaning of this much-abused term, as understood and intended by the present writer, is defined and discussed in an earlier article (Decker, 1952).

The author is Chairman of the Audio-visual Department of the Brooklyn Botanic Garden.

A very different interpretation of Lundegårdh's data is possible: the oxalis plant reached a maximal photosynthetic rate at a much lower light intensity and is therefore more "efficient." This interpretation appears to be based on the shapes of the curves rather than their heights. However, it actually requires an equating of the maxima as shown in Figure 2. Thus maximal rate has been used as the common denominator for the comparison, and the assumption is required that maximal photosynthesis has the same ecological value for both species. This assumption can be supported rigorously for only one kind of plant behavior, dry weight increment. A plant increases in dry weight in direct proportion to its photosynthetic rate, and maximal photosynthesis implies maximal dry weight increment. To extend the interpretation to other kinds of plant behavior would require that the relationship be established between photosynthesis (or dry weight increment) and the other kinds of behavior. Thus, even with this second interpretation no broad ecological significance can be attached directly to the difference shown between the two species.

Lundegårdh's interpretation was repeated by Maximov (1938) by Baker (1950). Some of the difficulty that can result is shown in Baker's discussion of tolerance. He stated (p. 141), "That tolerant species should be more efficient in carrying on photosynthesis at low light intensities than intolerant species would seem almost axiomatic from their definitions." He found, however, that the available evidence seemed to contradict rather than support his expectations. For example, his Figure 43C seemed to show that the intolerant Scotch pine was more "efficient" than the tolerant Norway spruce. A sounder interpretation is that the spruce required only 32 percent of full sunlight in order to reach a maximal photosynthetic rate, whereas the pine required full sunlight, and what this means ecologically remains to be determined.

Other recent attempts to draw broad ecological inferences from direct comparisons between species on the basis of photosynthetic rate or dry weight increment where unit amount of leaf is used as the common denominator, for example, Blackman and Wilson (1951), Kozlowski (1949) and Williams (1946), appear to be subject to the same major limitations. Much attention has been given to the problem of a single, ideal denominator, but there probably cannot be a universal denominator which will translate measurements of photosynthesis directly into reliable, broad ecological indexes (e.g. successional tendency), because the several aspects of ecological success (dry weight increment, growth, reproduction, survival, drought resistance, etc.) are not necessarily closely and positively correlated.

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Poor Survival and the Physiological Condition of Planting Stock

BY

EDWARD C. STONE

OVER TWELVE MILLION tree seedlings have been planted in California during the last five years at a cost of $830,000.[1] Accurate survival data on these twelve million seedlings are not available. The best estimate, however, places it considerably below fifty percent.[2] This poor survival is obviously costly and of considerably concern to those responsible for planting in California.

Part of the planting failures are attributable to rodents, livestock, and competing vegetation.[3] On the other hand, there are instances in which the reason is not apparent; not even the long summer drought nor the high temperatures associated with California's Mediterranean-type climate are satisfactory explanations.

For some time the author has felt that the failures are related to the physiological condition of the planting stock. This concept is not by any means original with the author. Both Fowells and Dunning of the California Forest and Range Experiment Station have implied as much in their effort to explain low survivals.

Additional support for such a viewpoint can be found in Wakeley's work on the southern pines.[4] He found that the correlation between morphological grades of stock and survival was often poor. The same morphological grade from different plant beds within the same nursery often gave very different survival values when planted together in the field.

The present preliminary study was undertaken for the purpose of determining whether or not physiological conditions resulting in low survival do occur. The questions of how such physiological conditions might be altered if they occur and to what extent they might be genetically controlled were not considered. In the light of the results presented below, however, experiments are now being set up to study the problem in its entirety.

Failure of either the root system or the

---

[1]Annual planting and stand improvement reports, U. S. Dept. Agr. For. Serv. Region 5, for fiscal years 1950–1954.

[2]Dunning, D. and B. M. Kirk. 1939. The Burney Spring plantation: a reforestation experiment in the brushfields of northern California. U. S. Dept. Agr. Calif. For. and Range Exp. Sta. unpub. rep.

[3]Fowells, H. A. and D. Dunning, 1948. A survey of National Forest Planting in California since 1930. U. S. Dept. Agr. Calif. For. and Range Exp. Sta. unpub. rep.

The author is Assistant Professor, School of Forestry, University of California, Berkeley. The work was carried on under University of California Agricultural Experiment Station Research Project 1577 in the Forest Physiology Laboratory.

[4]Wakeley, P. C. 1954. Planting the southern pines. U. S. Dept. Agric. Agric. Monogr. No. 18. 233 pp.

top, or both, to develop properly would be evidence of a potentially detrimental physiological condition. If the root system did not increase in size at a fairly rapid rate, either by elongation or regeneration, the seedling would die of drought when the moisture content of the soil surrounding the roots approached the wilting point. Lack of top development, on the other hand, probably would not become critical in itself during the first year after planting. For this reason the absence of root development was the criterion used in this study to indicate an unsatisfactory physiological condition of the seedling.

Materials and Method

The experiment consisted of:

(a) planting fall-lifted nursery stock in one-gallon cans,
(b) moving these cans into the greenhouse where favorable growth conditions were maintained,
(c) washing out these seedlings after 60 days to observe their root development, and
(d) replanting these seedlings in the same cans in order to observe their survival 120 days later.

Ponderosa pine (*Pinus ponderosa*) and red fir (*Abies magnifica*) planting stock was obtained from the United States Forest Service nursery at Oakdale; Jeffrey pine (*Pinus jeffreyi*) and white fir (*Abies concolor*) planting stock from the California Forest and Range Experiment Station nursery at Pinecrest; and Douglas fir (*Pseudotsuga menziessii*) from the California State Division of Forestry nursery at Fort Bragg.

The stock from Oakdale and Pinecrest was lifted during the second week of November, 1953 in the rain, carefully packed in sphagnum moss and transported to Berkeley the same day. It was planted in cans two weeks later. The stock from Fort Bragg was lifted in the middle of October and then stored at 38° F. in a cold storage plant in Eureka until it was shipped to Berkeley in February, 1954. This stock was planted in cans during the first week of March. All stock when received in Berkeley was placed in cold storage at 41° F. until used.

The seedlings were removed from the gallon cans by a low-pressure stream of water from a garden hose. The can was turned on its side and the hose, with the water turned on, forced in along the upper edge. The soil and the water flowed out together leaving the root system exposed. Where the seedling failed to show root development the soil was sifted through a quarter-inch sieve to determine whether or not any new roots had been inadvertently broken off.

Each species was represented by five samples of 10 seedlings each. All seedlings were root-pruned to approximately 5 inches so that they would fit into the gallon cans.

The soil used to fill the cans was sandy loam from a mixed-conifer stand growing on a good site near Pinecrest.

Results and Conclusions

Sixty days after the seedlings had been planted in the gallon cans and brought into the greenhouse, they all appeared healthy. The only top growth that had occurred during this time was terminal bud breakage in ten of the ponderosa pines.

When the seedlings were washed out of the cans at the end of the 60-day period, a pronounced difference in root development was evident. All the species tested showed some root production failures. In the particular lots studied, ponderosa pine showed the lowest average number at 16 percent, while Douglas-fir showed the highest at 40 percent. The results for all the species are shown in Table 1.

The fact that the standard error of the mean (S.E.) is large should not be disturbing. It is in keeping with the size and number of samples used.

Close examination of both seedlings that produced roots and those that failed to do so did not reveal any external morphological differences. Figures 1 to 5 show typical seedlings of each species, with all new roots painted white to make them photograph clearly.

TABLE 1. Root production failure on five different species of transplant stock.

Species and Nursery	Time of lifting	Time of planting	Kind of Stock	Percent without new roots after 60 days Mean	S.E.	Percent without new roots after 180 days Mean	S.E.
Pinus jeffreyi (Pinecrest)	fall	fall	2-0	20	±4.5	18	±4.0
Abies concolor (Pinecrest)	fall	fall	2-0	28	±4.0	20	±3.0
Pinus ponderosa (Oakdale)	fall	fall	1-1	16	±4.0	12	±2.5
Abies magnifica (Oakdale)	fall	fall	1-1	24	±4.0	24	±4.0
Pseudotsuga menziessii (Fort Bragg)	fall	spring	1-1	40	±4.5	40	±4.5

It thus appears that there is some physiological condition associated with the ability of seedlings to produce roots which cannot be associated with any specific external morphological difference.

Some objection might be raised to pruning to 5 inches all the roots of the seedlings used in this study instead of to 8 inches,

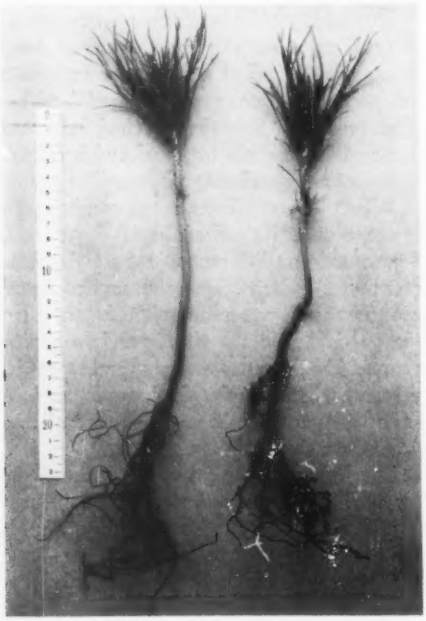

FIGURE 1. Fall-lifted, 2–0, Pinus jeffreyi *seedlings after 60 days in the greenhouse. On the right, representative of the 80 percent that had produced roots; on the left, representative of the 20 percent that had not.*

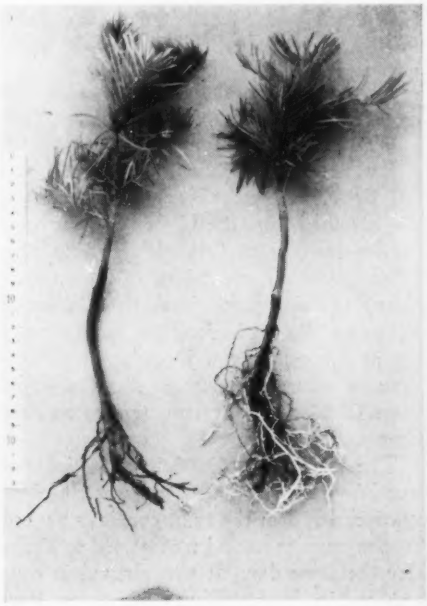

FIGURE 2. Fall-lifted, 2–0, Abies concolor *seedlings after 60 days in the greenhouse. On the right, representative of the 72 percent that had produced roots; on the left, representative of the 28 percent that had not.*

as is standard practice in field planting in California. Admittedly, considerably more of the root system was removed by pruning to 5 inches than to 8 inches. This in turn reduced the total number of new roots developed in the first month and might well influence survival of field-planted seedlings. When new root development did take place, however, some roots always developed on the older upper portion of original root system, (see Figures 1 to 5). Therefore, since the roots of all stock were pruned to the same length, and since new root development was not restricted to the lower portion of the initial root system, the severe pruning practiced was considered unimportant in these initial experiments.

One hundred and twenty days after replanting, which was 180 days from the beginning of the experiment, almost all the seedlings which had not produced roots in the first 60 days were dead. The tops were dry and brown and the needles had started to fall. A few were still alive and when re-exposed showed new root development (Table 1). Apparently, the physiological condition that prevented root production during the first 60 days after planting was not sufficiently altered in the next 120 days to allow new root development to take place.

Although the number of trees used in the experiment was not large, it was sufficient to demonstrate that a physiological condition related to low survival did exist in some seedlings of each species studied. On the other hand, the limited number of trees used as well as the method of selecting

FIGURE 3. Fall-lifted, 1–1 Pinus ponderosa *seedlings after 60 days in the greenhouse. On the right representative, of the 84 percent that had produced roots; on the left, representative of the 16 percent that had not.*

FIGURE 4. Fall-lifted, 1–1, Abies magnifica *seedlings after 60 days in the greenhouse. On the right representative of the 76 percent that had produced roots; on the left, representative of the 24 percent that had not.*

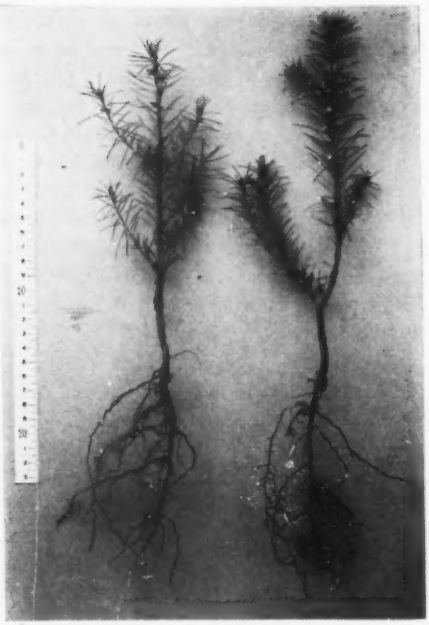

FIGURE 5. Fall-lifted, 1–1, Pseudotsuga menziessii, *seedlings after 60 days in the greenhouse. On the right, representative of the 60 percent that had produced roots; on the left, representative of the 40 percent that had not.*

lots of stock from the nurseries prevented any comparison of species, nurseries, or stock treatment.

A higher percentage of root production on seedlings from these same lots planted in the field would not be expected. Any difference should be in favor of the greenhouse-grown seedlings since the soil there was maintained at field capacity, while in the field the soil within the seedling root zone starts at field capacity in the spring and approaches the wilting point by late summer. Root production on field-planted seedlings presumably would be hindered by low soil moisture long before the wilting point is reached.[5]

Such results as these make one wonder how many million seedlings planted in California have been physiologically unsatisfactory, and thus, for practical purposes, dead when planted. Although the number cannot be computed from the data presented here, the indication is that it has been large.

[5]Reed, John F. 1939. Root and shoot growth of shortleaf and loblolly pines in relation to certain environmental conditions. Duke U. Sch. of For. Bull. 4. 52 pp.

The Current Status of Oak Wilt in the United States

BY

GEORGE H. HEPTING

FEW TREE DISEASES have commanded the national attention given oak wilt. Having observed the almost complete demise of the American chestnut from blight, the tremendous toll of the Dutch elm disease and elm phloem necrosis, and the cost of holding the white pine blister rust in check, even the layman is becoming apprehensive of any tree disease that threatens an important species.

Oak wilt has probably been active in Wisconsin and Iowa for 30 to 40 years or more (Fig. 1). It was reported as a fungus disease in 1942, and described in detail in 1944 by Henry *et al.* Estimates of its occurrence prior to that date are based upon old reports of oaks dying with wilt-like symptoms. As the potentialities of this disease became known in the 1940's, it began to receive major research attention, particularly in Wisconsin and Iowa. By 1950 the Federal Government was conducting surveys for the wilt in several States and also starting research; several universities were active in research; and some States were starting surveys. That year the National Oak Wilt Research Committee, composed of members of the hardwood industry, was formed, and in the years since, this group of private operators has given important financial support to oak wilt research at six universities and greatly stimulated the entire research effort against the disease.

FIGURE 1. A red oak dying of the wilt disease in North Carolina.

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The Wilt Fungus and Its Manner of Infection

The cause of the wilt is a sapstream-invading fungus named *Chalara quercina* by Henry in 1944 and later *Endoconidiophora fagacearum* by Bretz (1952), who discovered the sexual spore stage. Hepting, Toole, and Boyce (1952) determined the fungus to be a heterothallic, self-sterile hermaphrodite, and that union of two types of the fungus, designated A and B, was necessary for the sexual spore stage to be formed.

The fungus needs a wound of some type to invade the outer vessels of the sapwood. Important new data and past evidence linking infection to wounding are well presented by Norris (1955). Strong evidence is accumulating from many sources that the main period of infection is from April through June, depending upon the locality, when the springwood vessels are being formed.[1] The sources of inoculum are spores produced on wilt-killed trees. Conidia have been demonstrated in vessels (Young, 1949) and might be carried from them by boring insects or birds, but the most obvious sources of both conidia and the more sticky ascopores are the fungus mats produced under the bark (Fig. 2). These mats, first reported by Curl *et al.* (1953) and well described by Leach *et al.* (1952) and Fergus (1953), form from two to several months after trees or parts of trees die, mostly in the fall and spring (Engelhard, 1955). They raise and crack the bark, emit an odor attractive to many insects, and under certain conditions produce great quantities of both kinds of spores which are readily carried both externally (Yount, *et al.*, 1955) and internally (Jewell, 1954) by certain of the insects that inhabit the mats, and also by

[1]Craighead *et al.*, 1953; Dorsey *et al.*, 1953; Jeffery, 1953; McMullen *et al.*, 1955; Norris, 1955.

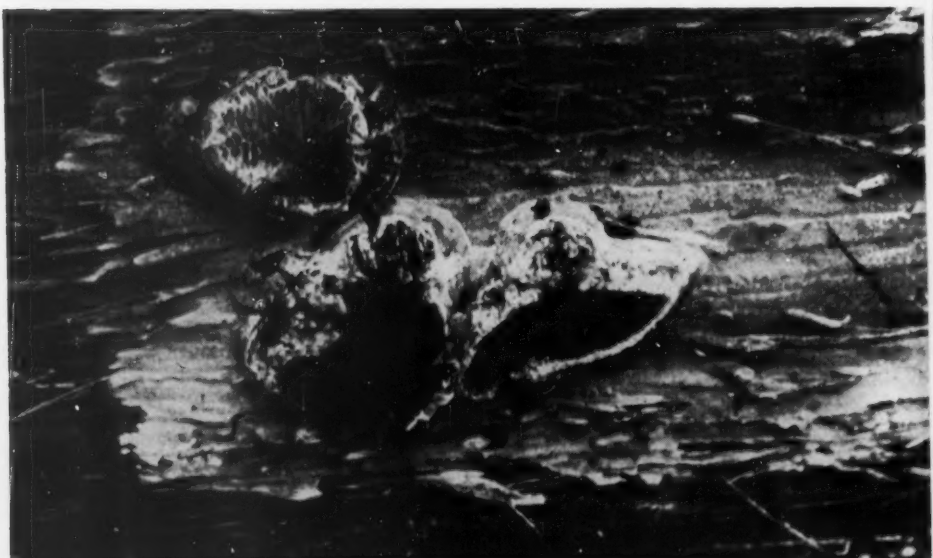

FIGURE 2. A spore-bearing mat of the wilt fungus, about twice natural size, under the bark of a red oak. On the mat are three of the cushions that raise and crack the bark.

squirrels (McNabb, 1954), and possibly by other animals and birds. Systematic attempts, however, to isolate the fungus from woodpecker beaks in oak wilt areas have failed to demonstrate viable spores on the birds (Tiffany *et al.*, 1954).

The story of infection from this point on is less well known. While spores have been found on many mat-visiting insects and on squirrels, the identity of the culprit or culprits that are mainly responsible for carrying spores to wounds under the right conditions for infection has not yet been fully established. Perhaps the prevailing view, substantiated by the important new evidence of McMullen *et al.* and Yount *et al.*, is that Nitidulid beetles which heavily colonize mats are mainly responsible for carrying spores to fresh, bleeding wounds in the spring. Wounds leading to infection have resulted from blazing, tree climbing, lightning, and several other causes. Morris and his coworkers (1955) collected Nitidulid beetles in the spring, dipped them in a solution of radioactive iodine, and released them in the vicinity of natural mycelial mats and freshly wounded trees. They were able to demonstrate that many of these beetles went either to fresh wounds or to fresh mats. Thus Nitidulids have been shown to feed on sporulating mats, to spermatize mats (Leach *et al.*, 1952), to carry viable spores on their bodies and in their intestinal tracts, to visit fresh wounds, and to accomplish infection. Some other insects, such as fruit flies (Bart and Griswold, 1953; Griswold, 1953), have been shown to accomplish some if not all of these acts.

Trees in the red oak group generally die the year they become infected, whereas those of the white oak group may not succumb for several years. If a diseased oak is root-grafted to a neighboring oak, the fungus can spread rapidly to it (Kuntz and Riker, 1950) and can live in the roots of a wilt-killed tree for at least 3 years after it dies (Yount, 1955).

All of the 50 species of oak tested against the wilt fungus have proved susceptible,[2] and so also have the American and Chinese chestnuts and members of the genera Castanopsis and Lithocarpus (Bretz, 1953; Hoffman, 1953).

The Range of the Disease

The Federal oak wilt survey program began in 1950 and has continued to date. These surveys were initially intended to determine the general distribution of the disease, and later to learn more about definite limits, local intensity, and more recently something about the damage being caused. As time went on, more and more States were conducting their own surveys, particularly those States east of the Mississippi River. Fowler (1954) has reported annually on the results of these surveys between 1951 and 1954. The known distribution on a county basis as of January 1, 1955, is shown in Fig. 3.

On the basis of the approximate year during which many of the infection spots were established (Fowler, 1952), it appears that oak wilt has been gradually spreading eastward. Clear evidence of spread and intensification of wilt has been obtained from recent studies in Tennessee, which showed the oldest infections (1945 or 1946) and the largest number of infections to be in Greene County, with the infection spots becoming more recent and fewer, by counties, as one moved through successive counties away from Greene County. True, Craig, and Cuppett (1955), reporting on the situation in West Virginia, state that, "Furthermore oak wilt is definitely spreading in those areas surveyed intensively in 1954."

Oak wilt may be limited by temperature, as indicated by the difficulty in isolating the fungus if the air temperature is close to 90°F. or above, and by an experiment (Anon., 1955) in which the fungus in the stems of young oaks remained alive for only 24 hours when plants were kept at

[2]T. W. Bretz has in press an article that brings to 50 the number of oak species shown to be wilt-susceptible.

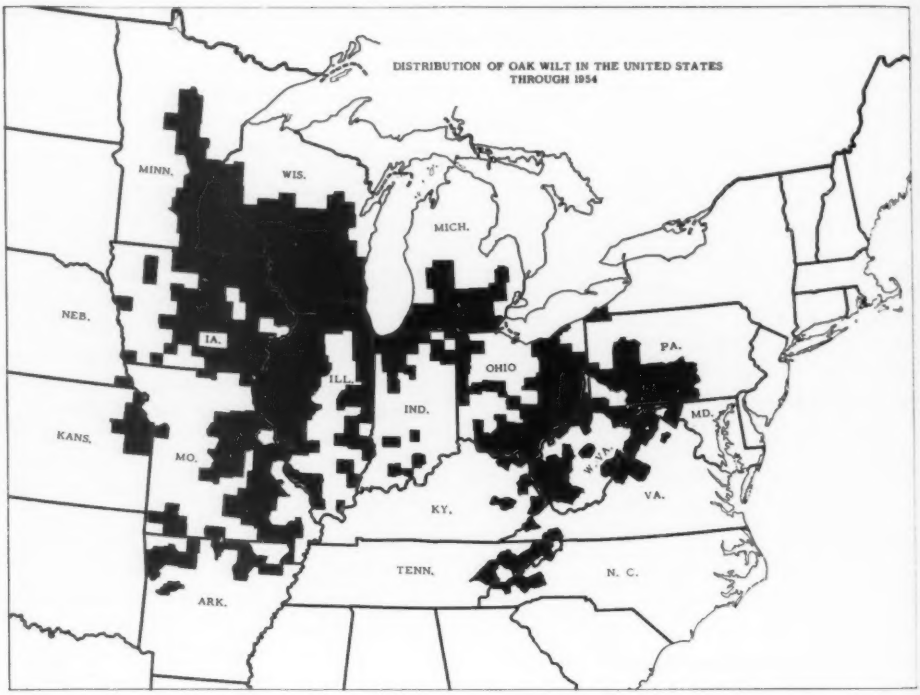

FIGURE 3. Known distribution of oak wilt in the United States as of January 1, 1955, by counties.

104°F. In this same connection, it is noteworthy that although wilt was found in several north Arkansas counties in 1950 and 1951, no active wilt has been confirmed in that State since. It is also noteworthy that the counties in which wilt has been found in the Southeast are largely in the mountains or foothills.

Oak wilt has caused conspicuous damage in many localities. Wysong's graphic account[3] of wilt damage in the Middle West and the destruction of oak on large areas in parts of Iowa (Brinkman, 1952; Dietz and Young, 1948) present a disturbing picture. Only recently, however, have figures become available on oak wilt losses over any areas as large as counties.

According to Ralph Anderson in an article in press, in 8 south central Wisconsin counties surveyed for wilt damage, about 2 percent of the oak type is disappearing every 7 to 10 years. In the 4 counties where damage was particularly severe, wilt has caused 4.4 percent of the oak type to go out of forest production in a similar period. In these 4 counties it could be expected that 30 percent of the area in oak types may no longer be supporting oak 50 years from now, at the current rate of loss.

Outside of Wisconsin and Iowa, oak wilt has caused damage in certain localities, but has been the cause of concern more because of the threat of the extent to which it might build up in the future than because of the relatively small economic loss to forests that it has caused to date.

[3]Wysong, N. B. 1949. Report on the oak wilt disease. Rept. to Bd. of For. Preserve Commissioners, Cook County, Ill. (Mimeo.)

Methods of Control

Each oak wilt infection center of one or more trees is likely to present a separate problem, requiring an individual approach. There are two basic control aims, however, common to all. The first is to prevent disease spread from the above-ground parts of the tree, and the other is to prevent under-ground spread through root grafts between a diseased tree and neighboring oaks of the same group. White oak group species may graft with each other, and red oak group species may graft, but the roots of whites and reds rarely graft with each other (Kuntz, 1952).

The sources of inoculum from diseased trees appear to be mainly the spore-bearing mats often produced under the bark after a tree or part of a tree dies of the disease. Such mats are not produced by all diseased trees, but when they form they constitute a great hazard. Trees with more than 80 heavily spore-bearing fungus mats have been observed in North Carolina and with over 240 mats in Iowa (Engelhard, 1955). The most likely means of transport of spores from mats to healthy trees is by insects, although birds and animals are possible vectors. The most effective means of checking overland spread is to cut and burn infected trees before mats are formed, and to poison and peel the stumps or char them well.

The "cut and burn" method will not always be feasible, especially in the case of large trees. Alternative methods may be used. The trees may be cut into lumber, the lumber dipped in a fungicide, and the slabs and slash burned.

In the case of a city tree, the slash may be incinerated and the trunk sections buried at the city dump or well charred. If none of the described methods can be used and the owner insists on using the tree trunk for firewood, a substitute but probably less effective spray treatment can be used. Immediately after felling, the bark should be sprayed with a suitable insecticide (Boyce, 1954). When the tree has been bucked up and ricked, the ricked wood should again be sprayed to reduce insect attack and fruiting of the fungus on exposed wood. Slash should be sprayed or burned or sprayed and later burned, and the stump poisoned first and then either charred, peeled, or sprayed.

Morris (1955), citing his own experiments as well as observations of Jeffery in Pennsylvania, reports that fungus mats were very seldom produced on trees felled in the earlier stages of wilt, particularly in early or midsummer, and not cut up. Shallow girdling followed by painting the cambium with sodium arsenite, and deep girdling when done in the summer resulted in very little mat formation. However, when trees were allowed to stand 6 weeks after complete defoliation and then were felled, one-third of them produced mats. In West Virginia deep girdling alone appeared to reduce mat formation (True *et al.*, 1955) in the summer. Peeling during a dry summer was effective in preventing mat formation in Pennsylvania (Fergus, 1953) and in North Carolina, but peeling at seasons other than spring is likely to be difficult. Certainly summer treatment as soon as possible after trees have been located is highly desirable.

Diseased trees cut in late summer or fall in North Carolina and Tennessee formed mats that same fall or else not at all, and thus these summer-felled trees might present little if any hazard the following spring at the probable time of maximum infection efficiency (Boyce, 1954a). When the bark of logs cut from wilted trees was sprayed with an insecticide, the number of living insects inhabiting the mats was reduced eightfold (Boyce, 1954).

Where important shade or ornamental values are involved, as in shade trees, the diseased tree should be disposed of, following one of the above methods, and if root grafting with neighbors is suspected, some root-severing as mentioned earlier would be helpful. Neighboring oaks should then be put under observation but not cut or poisoned unless they become diseased. Closely neighboring oaks of even the same species are not necessarily joined by root grafts.

Hope has been expressed that the research being conducted on chemotherapy will succeed in providing means of combating the oak wilt fungus in individual trees even after infection has taken place (Hoffman, 1953a), although the treatments most promising thus far have failed to kill the fungus in the trees that showed some temporary recovery.

In the case of woodlands, the wilting trees should be disposed of, using one of the methods indicated above, and then it is sometimes advisable to poison the oaks within a 50-foot radius, using Ammate, 2,4,5-T or other effective silvicide, or cut them and poison their stumps. If the owner is reluctant to agree to poisoning measures, then the area might simply be put under observation after removing the diseased tree, and any additional diseased trees disposed of as they appear, until below-ground spread stops for lack of graft union with similar oaks. Another method of checking root-to-root spread is to trench or slice deep enough to sever any roots that might connect a diseased tree with its neighbors (Kuntz and Riker, 1950). As mentioned earlier, each area is likely to present its own problems.

The Status of Control of Oak Wilt

The foregoing account of the current status of oak wilt is necessary background to a consideration of control. Thus far no oak wilt control is under way in some of the worst-affected States, beginnings in control have been made in others, and in some States systematic attempts are being made to eliminate the hazard of spread from infected trees as they are found.

Oak wilt continues to be a source of concern in spite of the strenuous efforts in research and control work in some States. Thus the technical committee of the lumber industry's National Oak Wilt Committee reports in February 1955 that, "The importance of the oak wilt problem is as great as ever . . ." (Anon.). The threat of build-up and blow-up is still with us if we fail to take control action.

In formulating an oak wilt control policy for a State or region, satisfactory answers must be supplied to five cardinal questions: (1) Why try to control it, (2) Is control possible, (3) Where should control be attempted, (4) What will it cost, and (5) What are the means of control?

Oak wilt control attempts would appear advisable for any State in which oak timber is a major element of the economy, and in which control costs would not be out of proportion to oak values. The weight of technical opinion is that, in much of the East, the risk of this disease increasing to serious proportions if unchecked is too great to warrant doing nothing in order to find out what oak wilt will do.

Can the wilt be controlled? The word *control*, as used here, means keeping losses to an acceptable minimum—not necessarily complete elimination. If oak wilt spread with the rapidity of the chestnut blight, success in control at this stage of the wilt's development over wide areas would indeed be unlikely. However, oak wilt ordinarily spreads slowly, and from many diseased trees probably not at all. Some groups of wilt-killed oaks have been observed about which no spread has been recorded for several years. Since under ordinary conditions overland spread is slow, we are presented with an unusual opportunity to suppress the disease in many States, thus holding losses to a low level.

If we wait until a large number of infection centers develop in some of the States that now have few infections, our chance to check the disease there without undue cost could be lost. Unforeseen conditions might rapidly convert our eastern infection centers, now possibly numbering a few thousands, into millions. It is pertinent here to mention that records are now available showing failure of oak wilt to spread when infection centers received a satisfactory treatment. Such results have been reported from Pennsylvania, Maryland, and Wisconsin.

Should statewide oak wilt control be attempted in all States where wilt has been

found? This is a controversial question. In several States between Missouri and Minnesota and eastward at least through Illinois, a thorough search for oak wilt infections and a systematic cleanup would undoubtedly be very expensive. Those States might prefer to await the results of control efforts in the more easterly States that have fewer infections before taking drastic control action. Salvage and cleanup where feasible, however, should be done in all States to minimize oak wilt losses.

How much will control cost? At present, any eastern State with oak wilt within its borders could eliminate the currently known infection centers and conduct an annual survey for the disease for a small fraction of what it spends on fire control. The costs of these control activities under various intensities of survey coverage and infection-spot elimination are available from such States as Pennsylvania, West Virginia, North Carolina, Ohio, and Michigan, and from the U. S. Forest Service. The experience of these agencies is available to others. Costs vary widely with intensity of treatment and with different forest conditions.

How should a control program be organized? In the absence of exact knowledge of how and when the oak wilt fungus is carried overland from diseased to healthy oaks, and in the absence of many years of experience in control work, there are differences of opinion as to the best and cheapest means of eliminating the hazard of spread from a diseased tree. Nevertheless, methods are available that can either completely destroy oak wilt trees (True *et al.*, 1955), or minimize the chances of spread from their mats (Boyce, 1954) and their roots (Kuntz and Riker, 1950), or both.

The responsibility for control of oak wilt now lies chiefly with the States and private owners on any lands other than Federal. If a State faced with this problem has no agency that could take over this function, it should create one, headed by a trained forester, pathologist, or entomologist. Legislation should be in force or enacted that would give the State means of persuading timberland or shade tree owners to instigate control measures or to permit the State to do what is necessary to eliminate critical tree disease and insect hazards. Several States have enacted or are contemplating legislation along these lines.

The decision on what to do about oak wilt control is one for each State to make. In a State, or on major areas within a State where oak wilt is becoming established, those in charge might elect to wait and watch what happens, hope for the best, and possibly lose the opportunity to control the disease, or they can organize such surveys, control, and follow-up as the situation requires.

Inquiries were made recently to determine what those States with oak wilt are doing about control. A digest of the replies is given in Table 1. No active oak wilt has

TABLE 1. Oak wilt control in 1954 and in prospect for 1955, by States.

States canvassed for oak wilt control	Total states	General control efforts in 1954		General control work planned for 1955		
		At all infection centers located	At only localized areas	None	At all infection centers located	At only localized areas
	Number of states					
States from Ohio and Michigan east and south	9	6	2	1[1]	7	1
States west of Ohio and Michigan	7	0	3	4	0	3

[1]Uncertain.

been reported in Arkansas or Nebraska during the past two field seasons. Of the 7 other States west of Ohio and Michigan in which oak wilt has been found, none had general control programs in 1954 and only 3 had major local control projects or intend to have localized control in 1955.

In contrast, from Ohio and Michigan east and south where oak wilt is less abundant, 6 of the 9 oak wilt States were conducting statewide control programs, 2 were conducting local programs, and only 1 had no control. In 1955 either 7 or 8 of the 9 eastern States will have general control programs and 1 or 2 will have localized programs. Thus, major efforts to hold oak wilt in control are under way in the East.

Now that oak wilt control is being attempted in many States, information on what these measures are accomplishing is becoming available. In a few years it should be possible to fully appraise these attempts, both local and statewide, and then a firmer basis for control policies will be provided.

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Fungi Associated With Cull in Redwood

BY

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PAUL C. LIGHTLE

MANY DESIRABLE QUALITIES make the heartwood of the coast redwood, *Sequoia sempervirens* (D. Don) End. suitable for a variety of uses, but probably its outstanding quality is its resistance to decay. Only a few species of fungi attack and destroy the wood. Even fewer are able to cause appreciable decay of the heartwood in living trees; yet because of these organisms, a large part of the volume in old-growth redwood stands has to be culled.

To supply information needed for the Forest Survey in California, a study was made of cull at 25 locations through the redwood region (Fig. 1). In this narrow strip of forested land along the coast of northern California is nearly 49 billion board feet, gross volume, of standing redwood timber, of which more than 11 billion board feet, or about 23 percent, is cull due to decay and associated defects.[1] Additional loss is caused by breakage when the trees are felled. The average extent of cull in trees of different sizes and the external indicators of cull in redwood trees have been evaluated for the southern and northern parts of the redwood region. This phase of the study has already been reported (Kimmey and Hornibrook, 1952). Information regarding the decay organisms responsible for the cull, and other results of the study are presented in this paper.

[1]Unpublished data from the Forest Survey, California Forest and Range Experiment Station.

In study areas situated in active logging operations, sample trees were selected to represent the range of site and diameter classes being cut in each logging operation. The decay organisms were identified from cultures obtained from the decayed wood. The methods described by Nobles (1948) and Davidson (1942) were used in identification.

Types and Causes of Rots

Earlier reports (von Schrenk, 1903; Fritz and Bonar, 1931) indicated that a single organism, *Poria sequoiae* Bonar, was probably responsible for all cull due to decay in the heartwood of living redwoods. In the present study we found two major types of decay. The most common type is a brown cubical rot caused by *P. sequoiae* (Fig. 2). The second type is a white ring rot (Fig. 3) and is especially prevalent in the northern part of the redwood region. This white rot, caused by *P. albipellucida* Baxter, was identified solely from cultures because fructifications of the fungus were never found on redwood.

It was difficult to isolate the causal fungi from these two types of decay in redwood.

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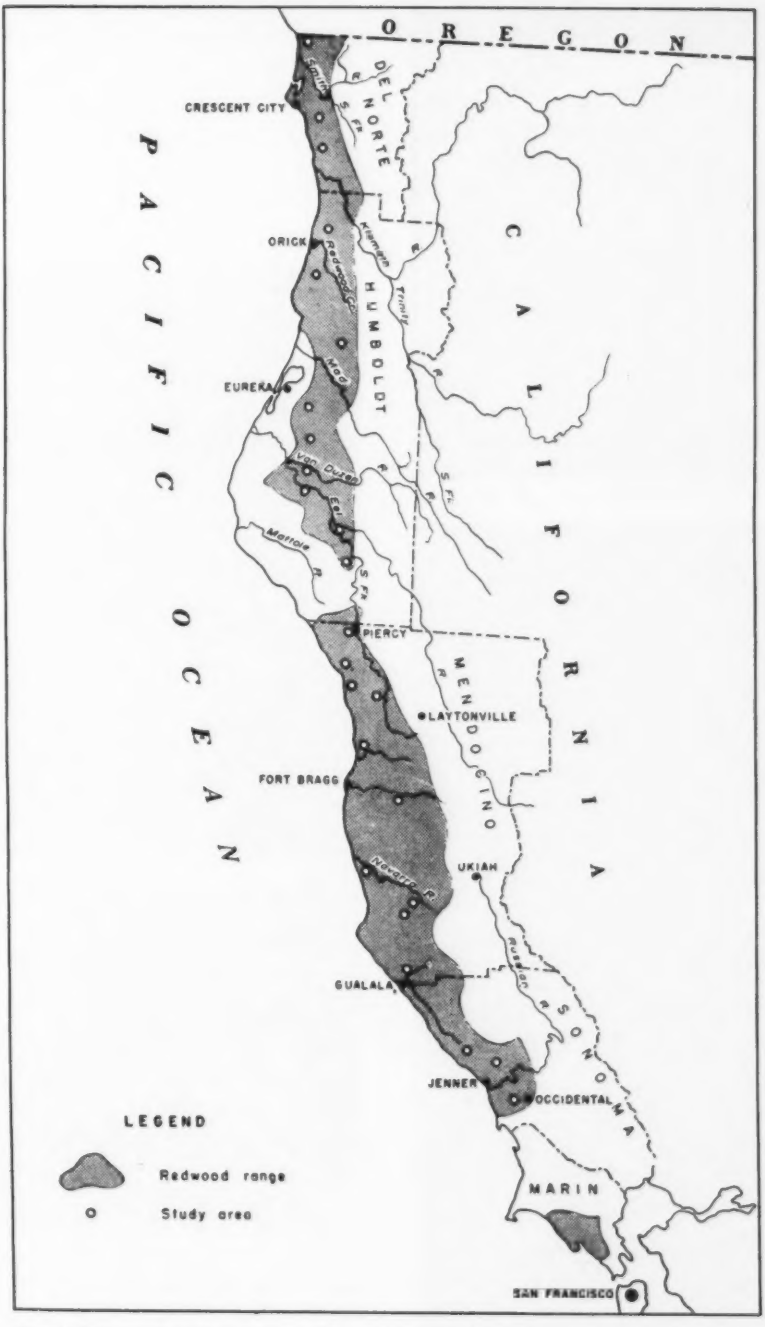

FIGURE 1. Location of the 25 study areas in the main commercial range of redwood.

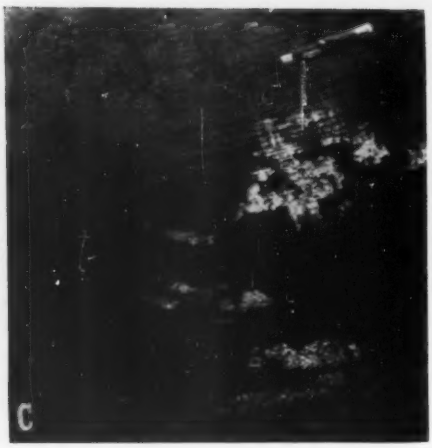

FIGURE 2. Brown cubical rot of redwood caused by Poria sequoiae. A. *End of an old-growth log showing a cross section of rot pockets.* B. *Longitudinal detail of rot pockets in a split log.* C. *Fructifications of the fungus on the end of a decayed log.*

FIGURE 3.—White ring rot of redwood caused by Poria albipellucida. A. *Longitudinal and cross-sectional view of a badly decayed log, showing stringy nature of the rot.* B. *Detail of the rot, showing laminations.*

In all cases of successful isolation, however, the causal fungus was either *Poria sequoiae* from the brown rot, or *P. albipellucida* from the white rot. For this reason we have assumed that they are the only two fungi associated with extensive cull. It is possible that other fungi which we could not isolate are involved, although all evidence is to the contrary.

Other decay fungi were present but caused negligible loss in volume in the heartwood. Three were identified as *Poria versipora* (Pers.) Rom., *Trametes carbonaria* (Berk. and Curt.) Overh., and *Fomes annosus* (Fries) Cooke. These fungi enter through fire wounds and cause limited decay in the immediate vicinity of the scars. *Polyporus abietinus* (Dicks.) Fries was occasionally found causing decay of sapwood in dead tops and branches, but caused negligible volume loss. Sterile black fructifications of an Ascomycete were occasionally found growing in association with exudate from rift cracks in exposed heartwood but apparently were not associated with decay.

An unidentified brown cubical pocket rot previously noted by Fritz and Bonar (1931) was commonly found causing limited decay in the thick redwood bark (Fig. 4). Our observations indicate that this rot is confined to the bark of the basal log. The decay is very similar in appearance to that caused by *P. sequoiae*, but the causal organism was never obtained in culture.

Description of Decays

Fritz and Bonar and von Schrenk have adequately described the brown cubical pocket rot caused by *Poria sequoiae*, but the white ring rot caused by *P. albipellucida* in redwood has not been described.

The earliest visible stage of decay caused by *P. albipellucida* in living redwood trees appears as a dark brown discoloration in the firm heartwood. Later the wood becomes softened and turns a lighter brown. In the advanced stage the wood is typically soft and cinnamon-brown. It separates along the annual rings as the early wood disintegrates (Fig. 3B). The wood surfaces between the laminae contain numerous minute, elongated pits. At times the surfaces of the laminae are coated with a black exudate, but only where the decay is near a rift crack. In the final stage the decayed wood is an orange-brown and the pitted surfaces of the late wood become hirsute with fine wood fibers, or the entire decayed mass may lose its laminate character and become fibrous (Fig. 3A).

Occasionally, in the late stages of disintegration, white mycelial flecks occur on the wood surfaces between laminae. This character, however, is not as common in redwood as Buckland (1946) found it to be in western redcedar (*Thuja plicata* Donn) decayed by the same fungus. Buckland also found that, in the late stage, the wood of western redcedar decayed by *P. albipellucida* was rarely of a fibrous nature.

In redwood the decay caused by this fungus is not confined to any one part of the tree. The decay is often associated with

FIGURE 4.—An unidentified brown cubical rot in the bark of redwood.

TABLE 1. Percent of sample trees infected with, and percent of the total rot[1] due to Poria sequoiae *and* P. albipellucida *in old-growth redwood, in each county of the main commercial range.*

County	*Poria sequoiae*		*P. albipellucida*		Trees infected with both fungi
	Total rot	Trees infected	Total rot	Trees infected	
Sonoma	99	81	1	7	2
Mendocino	97	85	3	7	5
Humboldt	76	81	24	15	12
Del Norte	45	63	55	73	48
All counties	72	80	28	18	12

[1]"Total rot" is the cull caused by decay, measured in cubic feet, to a 4-inch top.
Percent of gross cubic-foot volume that was cull, by counties: Sonoma 18.8, Mendocino 19.8, Humboldt 23.5, Del Norte 33.8.

rift-cracks through the center of the heartwood. The fungus appears to spread rapidly over the surface of the wood exposed in the rift-crack. From there it penetrates radially at a slower rate.

Decay in the incipient stage, caused by both fungi, is firm and appears as normal heartwood except for the discoloration. Affected wood is usually dark brown, but at times is almost black. Such wood, locally called "black heart," is culled or degraded in lumber manufacture, and is of value only for restricted uses where strength and discoloration are not factors and where the wood will not be in contact with the ground.

Besides the two decay fungi, cultures from this darkened heartwood yielded several different non-decay organisms. Common among these were staining fungi. One, which in the conidial stage is like Leptographium, was isolated most frequently. Yeasts, and several other groups commonly developing conidia, were also prevalent.

Occurrence of Decay

In this study 495 trees were examined. Of the total, 336 trees contained rot caused by *Poria sequoiae* only, 28 had rot caused by *P. albipellucida* only, 61 contained rot caused by both organisms, and 70 had no rot. In the northern part of the commercial range of redwood, decay caused by *Poria albipellucida* was responsible for more cull in living redwood than that caused by *P. sequoiae* (Table 1). Together these two fungi caused practically all of the cull due to decay in standing redwood tres. Decay in the incipient stage accounted for about one-third of all the cull in the heartwood of old-growth redwood (Kimmey and Hornibrook, 1952).

Entrance Courts

Most decay was associated with fire wounds and dead or broken tree tops (Table 2). A wound of either type becomes progressively more extensive with time. Consequently, when the wounds are old and large, it is often impossible to be certain where the exact entrance occurred. In the more recent wounds, however, it was determined that the heart-rot fungi commonly gained entrance to the heartwood through dead and decayed sapwood.

It is probable that many fire wounds are started by the burning out of decayed patches in the thick basal bark. The unidentified brown pocket rot, commonly found in the bark (Fig. 4), was never found to connect at any place with decay in the wood. In younger trees relatively recent fire scars were definitely determined to be entrance courts for the heart-rot fungi. Large basal fire wounds are formed by the repeated burning out of decayed heartwood. When the burned-out portion extends beyond the center of the heart-

wood, the wounds are locally referred to as goose pens.

Extensive heartwood decay, in both early and late stages, was found in association with broken tree tops. However, many of the larger broken tops were extensively decayed at the time the current break occurred. This indicates that the primary entrance was either through the unbroken dead top or an earlier break higher in the tree. Entrance courts are sometimes hidden or completely obscured after infection has occurred, as was demonstrated by a supplemental cull study in second-growth redwood. In this study *P. sequoiae* was occasionally found causing decay in small trees. Dissection and close examination of one tree showed that the fungus had entered through a broken leader. A new leader had developed, and the wound had healed so perfectly that there was no external indication of the old break.

Bole wounds other than those caused by fire and broken tops were somewhat less frequent, but they also were entrance courts for decay fungi (Table 2). We found no evidence to indicate that the heart-rot fungi enter the bole through dead or broken branches. As far as could be determined, entrance courts for *P. albipellucida* are the same as those for *P. sequoiae*.

Discussion

Fritz and Bonar (1931) considered that *P. sequoiae* typically causes only a butt-rot. Because they presumed that infection almost always occurs through fire scars, and they could find no connection between the basal rot and a similar decay in the tops, they considered that the decays were possibly caused by different organisms. Our studies show that decay caused by this fungus may occur in heartwood at any point in the bole, and the fungus may enter wherever heartwood is exposed in the bole.

The increase in incidence of *P. albipellucida* from Sonoma County northward in the redwood region may possibly be associated with the range and abundance of western redcedar. Buckland (1946) found that *P. albipellucida* caused more than 40 percent of the decay infections in redcedar on the coast of British Columbia. Although western redcedar ranges south to Mendocino County, its occurrence there is infrequent. It is not a significant element of the timber stands in the redwood region south of the Mad River, and is of economic importance as a timber tree only in northern Del Norte County. There appears to be a direct correlation between the incidence of western redcedar and the abundance of *P. albipellucida* rot in redwood. Buckland

TABLE 2. Entrance courts for P. sequoiae *and* P. albipellucida *in standing old-growth redwood.*

County	Number areas Sampled	Infections associated with— Fire wound Total No.	Fire wound With P.s. Pct.	Fire wound With P.a. Pct.	Dead or broken top Total No.	Dead or broken top With P.s. Pct.	Dead or broken top With P.a. Pct.	Other wound Total No.	Other wound With P.s. Pct.	Other wound With P.a. Pct.	Infections of undetermined origin Total No.	Undetermined With P.s. Pct.	Undetermined With P.a. Pct.
Sonoma	3	25	100	0	7	86	14	5	60	40	24	92	8
Mendocino	10	106	94	6	61	98	2	17	94	6	77	91	9
Humboldt	9	85	88	12	65	97	3	14	86	14	66	80	20
Del Norte	3	27	37	63	44	61	39	2	0	100	42	31	69
Total or Average	25	243	86	14	177	88	12	38	82	18	209	76	24

P.s. = *Poria sequoiae*
P.a. = *Poria albipellucida*

reported that the fungus fruits on western redcedar slash in British Columbia. We found no fructifications of the fungus on either redwood or western redcedar in California; however, we made no special search for fructifications on redcedar. A probable explanation for the association of *P. albipellucida* in redwood with the occurrence of western redcedar is that the fungus fruits on the latter species and rarely or not at all on redwood.

Summary

Two types of decay cause extensive cull in the heartwood of living redwoods: A brown cubical pocket rot caused by *Poria sequoiae* Bonar and a white ring rot caused by *P. albipellucida* Baxter. These two rots cause virtually all cull due to decay in redwood stands. The former is most severe in the southern, and the latter in the northern part of the tree's range.

Fire scars, broken tops, and other wounds exposing heartwood in the bole are the main entrance courts for rot-causing organisms. Broken branches were not found to be entry points for the organisms causing decay. Entrance courts are the same for both *P. sequoiae* and *P. albipellucida*.

All successful cultures from the brown cubical pocket rot were identified as *P. sequoiae*, and those from the white ring rot as *P. albipellucida*. These two fungi are considered to be the only ones associated with extensive cull in redwood.

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Selection of Pine Super-seedlings —an Exploratory Study

BY

BIRGER W. ELLERTSEN

THE TERM "SUPER-SEEDLING" designates an exceptionally tall individual seedling in a uniform nursery seedbed. To select super-seedlings from a production nursery, to outplant them, and to preserve those showing continued superiority for propagation, breeding and seed production identifies the objective of a study TVA started in 1951. The purpose of this report is to briefly outline the basis for undertaking the study, describe how selections were made, and give preliminary indications that have shown up to date.

Selections of exceptionally tall individuals from nursery seedbeds is an empirical approach to the determination of the inherence of early vigor. Modern nursery practice has developed to a stage where huge quantities of relatively uniform planting stock are produced each year. Nurserymen repeatedly have observed occasional oversize individuals that stand out in uniform pine seedbeds. These seedlings are often eliminated in grading, since they are harder to handle and tend to increase packing and planting costs. Thus there is a question as to how these "super-seedlings" would develop compared with the mass of planted seedlings, and whether they might produce inherently superior trees.

The possibility of exerting a positive influence on the production of future forests by nursery selection has been pointed out by Lindquist (1948). Sherry (1947), working with longleaf pine in South Africa, selected the largest seedlings on planting trays and established two test plots, one containing vigorous and the other average or normal seedlings. After five years, over 70 percent of the trees on the vigorous plot exceeded 20 feet while none in the normal plot had yet attained this height.

Hybrid vigor, seed size, and local variations in seedbed fertility are sometimes responsible for unusual seedling size. In Sherry's case some of the vigorous trees proved to be hybrids, although after five years, seven true longleaf pines were as vigorous as the best of the hybrids. Aldrich-Blake (1930, 1935), working with Corsican pine, and Gast (1937) and Mitchell (1934, 1939), working with Scots and white pine, observed a direct relationship between seed weight and the weight of seedlings at the end of the first growing season. The difference, however, in seedling size associated with original size of seed gradually wears off. Both Spurr (1944) and Righter (1945) observed that the effect of seed size on seedling size was at first pronounced, but that it later diminished in contrast with the sustained effect of other factors associated with seed origin. Older studies reviewed by Baldwin (1942)

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TABLE 1. Status of pine super-seedling selections from Clinton Forest Nursery, 1954.

Pine Species	Seedlings examined in nursery seedbeds		Number of super-seedlings		
	Year	Number	Selected and planted	Surviving fall 1954	Outgrew controls
Loblolly	1951	6,412,000	33	27	12
	1952	3,595,000	18	9	6
	1953	6,289,000	30	29	21
	1954	16,265,000	78	78	--
Shortleaf	1953	2,300,000	10	10	8
	1954	1,735,000	6	6	--
White	1954	3,758,000	9	9	--
All pines	1951-54	40,354,000	184	168	--

and the U. S. Forest Service (1948) indicate that seed size may affect the growth of pine up to the ninth year after planting. In nurseries the occurrence of seedlings of unusual height in clumps or bands is ascribed to local differences in seedbed condition. Such seedlings are readily distinguished from the lone super-seedling that stands out above its neighbors.

The TVA nursery at Clinton, Tennessee, afforded an opportunity to try nursery selection on a systematic basis and to evaluate the practical feasibility of using this method to segregate exceptionally vigorous trees. The nursery produces large quantities of loblolly pine and significant amounts of shortleaf and white pine seedlings, representing progeny of mixed parentage from different selected sources. The study is now entering its fourth year, and differences in seedling behavior are becoming apparent. Procedure followed in conducting the test has been described in the work plan appended to the report on "Testing Tree Progeny" (Wiesehuegel, 1952).

Selection is made on the basis of height and is done in the fall immediately before lifting. First, a reconnaissance of the beds locates exceptionally tall seedlings. These are marked and measured, along with the heights of 25 adjacent seedlings. The average of each 25-seedling sample is then computed and subtracted from the height of its corresponding tall seedling. Those with the greatest difference, chosen at a rate of roughly one for every 200,000 seedlings[1] in the seedbed, are considered super-seedlings and are transplanted to the arboretum. Each super-seedling is paired with a control or check seedling taken from the same spot in the seedbed and having approximately the computed average height of the 25-seedling sample. Annual height measurements are made of all trees up to the age of five years in the arboretum.

Since fall 1951, 184 super-seedlings have been selected from 40 million seedlings and 168 are still living in the arboretum (Table 1). The most striking feature about the super-seedling planting is the variation in height of the older trees. For example, 12 of the 27 surviving 1951 selections have continued to grow faster than the controls. In fall 1954 these super-seedlings averaged 7.0 feet in height, their controls 5.0 feet (Table 2). The best selection of this group was 8.8 feet tall as compared with 4.7 feet for its control. It is interesting to note that this tree did not stand out from the rest the first year, being only 0.9 foot in contrast with an average height of 1.3 feet for all super-seedlings. On the other hand many of the super-seedlings have been outgrown by their checks. At least a

[1]In the case of the 2-0 white pine planting stock, tall seedlings occurred less often than in the other species and the final selections ran at a rate of about one for every 425,000 seedlings.

TABLE 2. Height of super-seedlings and corresponding paired controls measured at one-year intervals.

Year measured	Average height of seedlings, feet				Height of tallest seedling, feet	
	All		Outgrew controls			
	Super	Control	Super	Control	Super	Control
	Loblolly Pine — 1951 Selections					
1951	1.3	0.6	1.1	0.5	0.9	0.4
1952	1.7	1.2	1.9	1.0	2.5	.9
1953	3.5	2.9	4.0	2.8	4.7	2.5
1954	6.2	5.3	7.0	5.0	8.8	4.7
	Loblolly Pine — 1952 Selections					
1952	1.4	.7	1.3	.8	1.4	.8
1953	2.0	1.2	2.2	1.3	2.0	1.3
1954	3.6	2.7	3.9	2.7	4.5	2.7[1]
	Loblolly Pine — 1953 Selections					
1953	1.3	.5	1.2	.5	1.1	.4
1954	2.6	1.5	2.7	1.4	3.0	1.3
	Shortleaf Pine — 1953 Selections					
1953	1.0	.4	1.0	.4	1.0	.4
1954	2.2	1.2	2.3	1.2	2.1	.8

[1] Estimated value based on all living controls of similar seed source and age since paired control for this super-seedling died.

part of this is attributed to variation in seed size. Screening the seed to size grades before nursery seeding was not done at the Clinton Nursery, but has been followed by Zobel in a similar study in Texas (Texas Forest Service, 1953). Comparisons that have been made so far are strictly preliminary but suggest a few of the super-seedlings may maintain vigorous growth beyond the point where effect of seed-size might be a major cause of their superiority.

Future plans in this study call for evaluation of the super-seedlings after five years' growth in the arboretum. The fifth-year height increment will be the basis for rating. The difference between each super-seedling and its paired control, measured in terms of the standard deviation of all controls, will be assigned a rating on the basis of probability: 0 for greater than 0.1, 1 for less than 0.1, 2 for less than 0.01, 3 for less than 0.001, and so on. Plans for additional continuance of the study call for re-evaluations and thinnings at intervals of five years. As time goes on we may be able to improve our selection techniques. Certainly, we should have evidence of whether nursery selection is a promising approach for the discovery of genetically fast-growing strains of forest trees.

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REVIEW by William A. Dayton
U. S. Forest Service

THE GERMAN legend on the jacket of this volume, freely-translated, reads: "990 forest-biology terms occur in the divisions of this lexicon, leading from the scientific Latin names to their equivalents in German, English, French, Spanish, and Russian. Corresponding foreign indexes in each of the five languages enable the user to find the appropriate pages."

The compiler is connected with the Forest Research Institute at Reinbek bei Hamburg, Germany, and, in her brief forword, names 19 people, including 3 Americans, who have assisted in her compilation. The work essentially is in two main parts: (1) A numbered alphabetical Latin list leading to the equivalents in the five European languages mentioned, and (2) the five separate German, Englist, French, Spanish, and Russian lists. As synonymous names are also numbered the main (Latin) list contains numerous duplications. A spot check indicates that the names of insects and arachnids represent about 35.3 percent of the whole; birds, 22.4 percent; fungi, 12.9 percent; mammals, 10 percent; trees, 8.2 percent; other flowering plants, 7.7 percent; and fish, 3.5 percent.

The fauna and flora covered are European, although, strange to say, the Hudson Bay marten is included. In some cases "Ams." is given in brackets as after "asp" and "trembling poplar," to indicate that the English name is American, although the entity referred to (in this case, *Populus tremula* L.) is European. Some of the English names appear abbreviated as in "large white" for *Pieris brassicae* L. It seems unfortunate that the English name "agaric" (pertinent to the harmless genus *Agaricus*) has here been employed for the chiefly toxic genus *Amanita*.

American foresters will find this book primarily of use in interpreting European (and perhaps especially Russian) literature on forest biology, where the different alphabetical language lists will help one to find the appropriate scientific and English names.

Controlled Pollination of Eastern Hemlock

BY

HANS NIENSTAEDT
HOWARD B. KRIEBEL

A VARIETY OF BAGS has been used in controlled pollination of trees. They vary in factors which have an important bearing on flower development: amount of light penetration, amount of heat absorption, and ability to allow water vapor penetration. Furthermore, they vary in their ability to stand up against the weather, in their efficiency as a pollen barrier, and in cost.

A tree breeding program of eastern hemlock was started in Connecticut in 1952, and it soon was found necessary to determine what type of bag was the most efficient in controlled pollination.

The experiment was designed in such a way that some information could be obtained on effects of light, heat, and humidity on the early development of the cones and seed.

Materials and Methods

Nine types of bags were used in the experiment, some of a type commonly used in pollination work, others especially chosen for their modifying effects on the environment. The types of bags and their characteristics are listed in Table 1.

The experiment was conducted during 1953, an excellent seed year for *Tsuga canadensis* (L.) Carr. over the entire range of the species. Two young trees which were flowering profusely were selected as female parents in the experiment.

Four stages in the development of the hemlock female flowers can be recognized during late April and early May, the time important in a pollination study. In the flowering stage (Fig. 1) the conelets are still surrounded by the bud scales near the base with only the edge of the lower bud scales beginning to turn back. The male catkins have not yet started to open. Bagging should be done at this stage or a few days earlier. In 1952 this stage could be recognized in and around New Haven, Connecticut on May 1. About a week later the second stage (Fig. 2) has been reached; the conelets are free of the bud scales over their entire length and all the cone scales, except those close to the tip of the conelets, are bent back. The first male catkins have started to shed pollen. This probably indicates the beginning of the period during which the female flowers are receptive to pollination. In about two days the third stage (Fig. 3) has been reached. This probably coincides with the period of maximum pollen receptivity. The cone scales are all turned back, the elongating stalk of the cones can be seen between the bud scales and the first conelets are turning into a drooping position. Practically all male catkins are shedding pollen. Stage four (Fig. 4) is reached in about 4 days.

Nienstaedt was with The Connecticut Agricultural Experiment Station, New Haven, and Kriebel is with Ohio Agricultural Experiment Station, Wooster.

FIGURE 1. The first or flowering stage of eastern hemlock, trees A and B, May 2, 1952, showing female conelets and clustered male catkins.

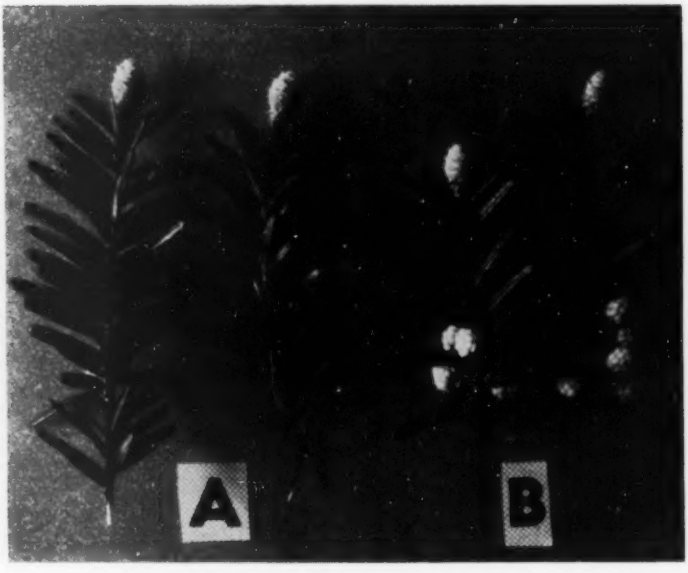

FIGURE 2. The second stage, May 7, 1952.

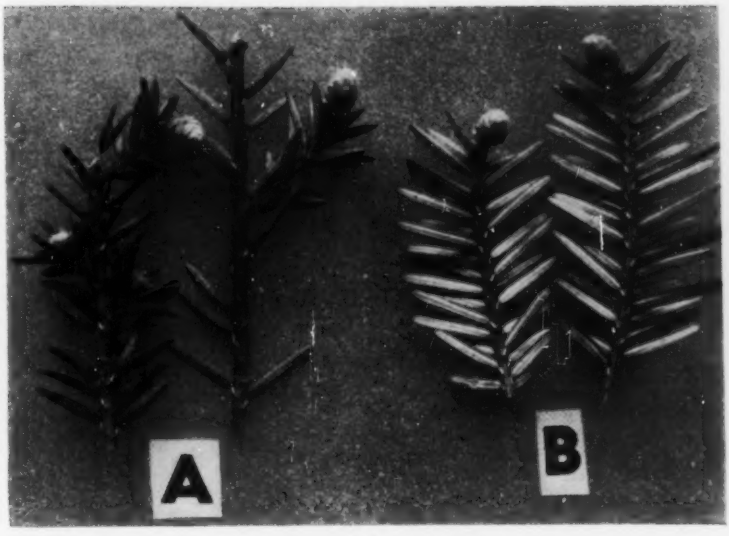

FIGURE 3. The third stage, probably coinciding with maximum pollen receptivity. May 9, 1952.

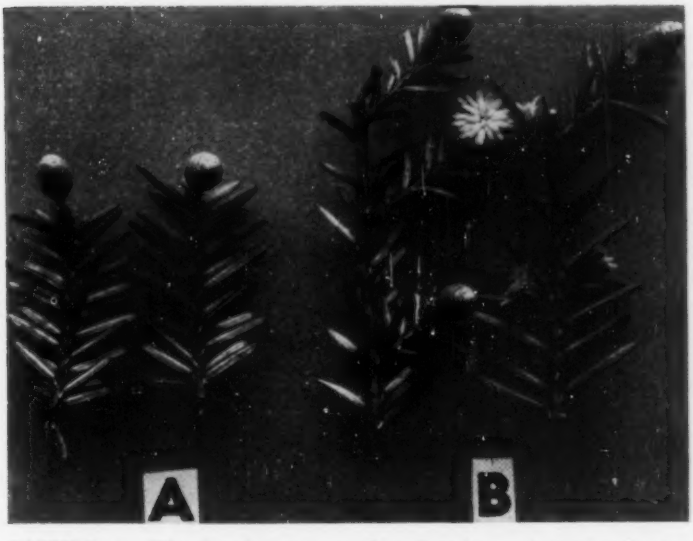

FIGURE 4. The fourth stage, conelets drooping and cone scales partially sealed. May 15, 1952.

TABLE 1. Different types of bags used and a description of their more important characteristics.

Type of Bag	Characteristics			
	Light penetration	Heat absorption	Moisture permeability	Resistance to weathering
Cloth[1]—black	low	high	high	good
white	medium	low	high	good
Kraft paper[2] painted—black	very low	high	low	medium
white	low	low	low	medium
Kraft paper[2] unpainted	low	medium	medium	medium
Parchment paper[3]	high	low	medium	low
Polyethylene	high	high	none	good
Polyethylene and Kraft	low	medium	none	good
Sausage casing[4]	high	high	medium	good

[1] Bags made of fine cotton broadcloth (160 threads to the inch) seams were folded double, and double stitched.
[2] 50 lbs. wet strength paper bags, glued with waterproof glue. Commonly used in pollination of corn.
[3] Parchment Ear-Tector bags, glued with waterproof glue.
[4] Visking cellulose sausage casing, 2¾ HS.

The conelets have all turned into a drooping position and the cone scales have closed up to a greater or lesser degree. Some pollen is still being shed. This stage probably represents the latest part of the period of pollen receptivity.

In this experiment the bagging was done during the early part of stage one and the pollination was done May 5, when the flowers had reached an early part of the third stage. A mixture of pollen from several different trees of the same species was used. From the results of the pollinations it was evident that the pollination was well-timed.

Fertilization in hemlock does not take place until some 6 weeks after pollination. It therefore seemed advisable to determine if bagging over different lengths of this period had any effect on the fertilization and seed development. Bags were accordingly left on for 20, 37 and 54 days respectively after pollination. These periods should have completely eliminated any chance of outcrossing, and should have been sufficiently long for any effects of the bags on the developing conelets to be manifest.

Two replicates of the treatments were made on the larger of the parent trees, but only a single replicate could be placed on the smaller tree. Temperatures in the bags are undoubtedly strongly affected by solar radiation; it was therefore thought that a difference in the results might show up between the north and the south sides of the tree. To obtain some information with regard to the temperatures reached in the different bag types on the north and south side of the tree a maximum-temperature thermometer was placed in one of each type of bag on the two sides of the larger tree. The thermometers were read at intervals during the period the bags were left on the trees.

The mature cones were collected as soon as they started to turn color in October. They were dried at room temperature and the seeds were removed by hand, making certain that no seed remained in the cones. The seed was cleaned and light seed removed, using an air-stream of constant force supplied by a vacuum cleaner for 30 seconds. Through several test runs this method had been found to clean the seed well without blowing over any full seeds. The number of good cones per bag and the total weight of filled seed was recorded.

The cleaned seed was stratified under moist conditions for three months and then planted in a modified type of Jacobson germinator. The number of germinated

seeds was recorded at intervals for ten weeks. Very little seed, however, germinated between the 7th and the 10th week.

Results

There were marked differences among the different types of bags in yield of viable seed, as determined by germination tests (Figure 5). Highest seed yields per cone (excluding insect-damaged cones) were obtained with white cloth bags. Parchment paper bags ranked next, then kraft. Both sausage casing and black cloth gave fairly good results on the north side of the tree, but poor results on the south side. Other types of bags yielded very little viable seed.

The average maximum temperature inside the bags during the period ranged from a low of 88 degrees Fahrenheit (31 degrees Centigrade) to a high of 110 degrees Fahrenheit (43 degrees Centigrade). As expected, temperatures were generally higher on the south side of the tree than on the north side.

In middle July it was discovered that the cones had been seriously damaged by insects; a lepidoptera larva was found in the cones, but it could not be further identified. Because of this reduction in seed yield, analysis of the effect of length of time of bagging on seed production was not possible.

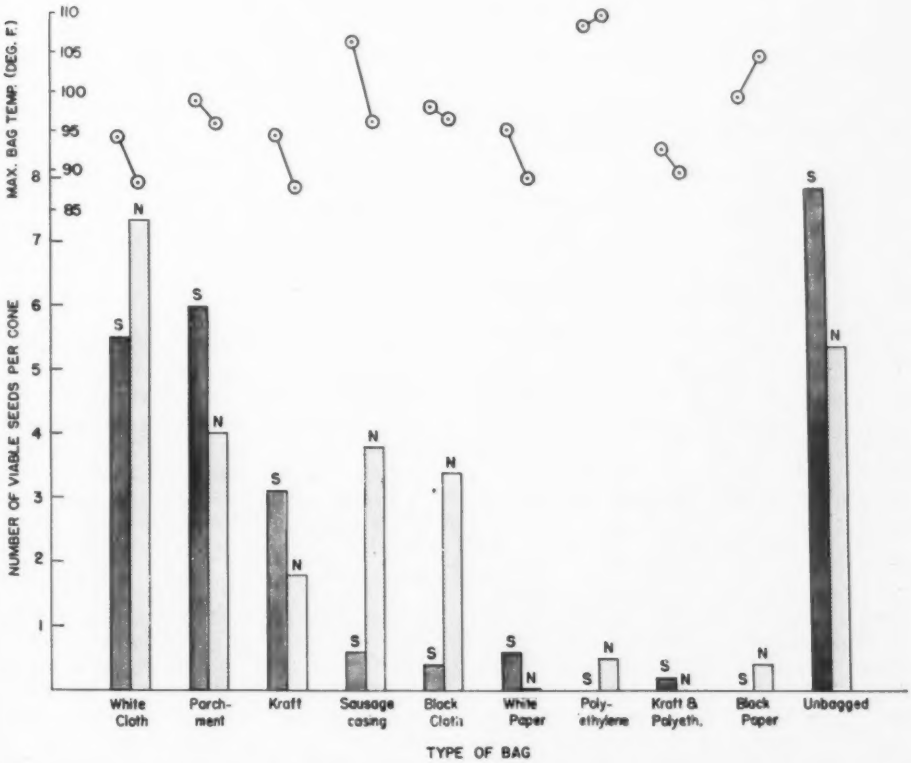

FIGURE 5. Relative effectiveness of each of nine types of bags for controlled pollination of eastern hemlock. Seed yields for south (S) and north (N) sides of trees are shown, also average maximum temperatures inside the bags. Based on weighted averages of two trees.

Discussion

High temperature due to direct solar radiation caused a severe burning and shriveling of hemlock cones in the transparent bags, particularly the sausage casing. In some cases both cones and needles were burned. Cones in the black paper bags were also affected in this way, and a few in the black cloth bags.

Low light intensity inside the bags was apparently a detrimental condition for cone development. A large proportion of the cones in the dark-colored bags were etiolated and non-productive. Kraft, kraft and polyethylene, and kraft bags painted white, also had some etiolated cones. Excess moisture caused a waterlogging of cones in polyethylene bags, resulting in a very low yield of viable seed.

Cones in the white cloth and parchment bags had practically no injury of the types just described. Both of these materials were satisfactory with respect to light penetration, heat absorption, and moisture permeability. Of the two, white cloth is recommended because of its superior weathering qualities. Neither parchment paper nor Kraft withstood heavy rains and high winds as well as cloth.

The results indicated that all types of bags used are satisfactory pollen barriers. There was no seed produced in any of these types of bags among the unpollinated controls.

Skogslexikon. Svenska–Engelska–Tyska–Franska.

(*Forestry dictionary. Swedish–English–German–French.*) *By M. E. Simonen. Svenska Skogsvardsföreningens Forlag, Stockholm. 1954. 284 pp. Sw. kroner 33.50.*

REVIEW by John A. Zivnuska
School of Forestry, University of California

THE TECHNICAL language of any profession involves both its own special words and phrases and special meanings for common words and phrases. The difficulties which this involves in translation are familiar to any forester who has attempted to read the literature of his field in a foreign language with only a general dictionary as an aid. The new forestry dictionary published by the Swedish Forestry Association is a major contribution in meeting this problem.

The arrangement of the dictionary is designed to facilitate translation from Swedish into English, German, or French. A comprehensive index, however, makes it possible to translate from any one language to any other three. The main section presents an alphabetical listing of 2,616 Swedish words related to forestry followed by their translations into English, German, and French in parallel columns. This is followed by an index of the words in each of these three languages, in which each word is keyed to the corresponding Swedish word in the main section by letter and number.

The selections of words is based on their usefulness in the Swedish literature. As a result, certain terms common in the other languages have been left out. For example, the logging "sulky" is listed but the logging "arch" is not. Considering the specialized interests of foresters who read the foreign literature, it is probable that each user of the dictionary will in time develop his own list of special terms which are not included. However, it appears that Mr. Simonen has done a thorough and well-balanced editorial job in a difficult field.

The translations are generally clear and accurate. Detailed paraphrases are presented in those cases in which there are no exact equivalents. The English translations give preference to Anglicisms. However, such familiar terms as "board feet," "cutting," "gasoline," and "lumber" are presented as Ameri anisms.

This dictionary is clearly a required item for every forestry library. In addition, some research workers will surely find it helpful to have their own desk copies.

Self-Compatibility and Effects of Self-Fertility in Western White Pine

BY

R. T. BINGHAM
A. E. SQUILLACE

THE KNOWLEDGE that certain monoecious plants like pines are in some degree self-compatible, i.e., capable of producing pollen that can fertilize ovules of the same tree, and self-fertile, i.e., capable of producing sound, germinable self-fertilized seed, is not new. The degree of self-compatibility and self-fertility, however, and its consequences are of such importance in tree-improvement programs that specific knowledge for each tree species under study is desirable. This paper contains new information of the degree of self-compatibility and self-fertility in western white pine (*Pinus monticola* Dougl.).

Controlled pollinated seed and seedling progenies here discussed were produced in a cooperative project in breeding blister rust (*Cronartium ribicola* Fischer) resistant western white pine (Bingham *et al.*, 1953). The development of white pine resistant to blister rust was given major impetus in this country about 15 years ago when work was started in Wisconsin by Riker and his associates (1943).

Except in a few tree genera that flower while quite young, work in tree improvement through the production and eventual crossing of inbred lines (as in maize) is not considered by forest geneticists to be of much promise. Rather, they recognize natural selfing as a potential problem in the production of improved seed.[1] Many workers, however, plan to employ self-pollinations as a means of exposing recessive genes (Orr-Ewing, 1954), of assuring the mating of similar genotypes while at the same time investigating effects of inbreeding (Bingham *et al.*, 1953), or as a rapid method for intensifying and fixing inherent characters (Schreiner, 1954).

Several species of conifers are known to include relatively self-compatible individuals. Among these are eastern white pine, *Pinus strobus* L. (Johnson,, 1945; Wright, 1953), Scotch pine, *P. sylvestris* L. (Dengler, 1952; Johnson, 1945), slash pine, *P. elliottii* Engelm. (Mergen, 1954), and Jeffrey pine, *P. jeffreyi* Grev. and Balf. (Righter, 1945). Pines believed to fall in the same category are Austrian pine, *P. nigra* Arnold (Johnson, 1948) and many of the white pines (Wright, 1953). Only a few years ago foresters accepted the idea that pines were generally self-incompatible (Dorman, 1950).

Four of five larch species (*Larix* spp.)

[1]Dengler, 1932; Forshell, 1953; Jensen, 1945; Johnson, 1945; Langlet, 1940; Langner, 1951; Mergen, 1954; Orr-Ewing, 1954; Wright, 1953.

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tested by Piatnitsky (1934) were found to be self-compatible, and Langner (1951) and Gothe (1952) confirm this evidence for two of the same species. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) was believed relatively self-incompatible by Allen (1942) and Duffield (1950), yet wide differences in self-compatibility and self-fertility were found in two trees critically examined by Orr-Ewing (1954).

Many angiosperm trees have been found self-compatible and self-fertile including green wattle, *Acacia decurrens* Willd. (Philp, 1946), black wattle, *A. mollissima* Willd. (Osborne, 1931), Siberian peatree, *Caragana arborescens* Lam. (Cram, 1952), many chestnuts, *Castanea* spp. (Clapper, 1954), maple, *Acer* spp., and oak, *Quercus* spp. (Piatnitsky, 1934).

Schreiner (1954) reports that there is evidence of some degree of self-compatibility in certain individuals of larch, spruce (*Picea* spp.), pine, hemlock (*Tsuga* spp.), yellow-poplar (*Liriodendron tulipifera* L.), birch (*Betula* spp.), and Alder (*Alnus* spp.). Piatnitsky states the belief that most important forest trees are somewhat self-fertile and, indeed, according to the evidence most of the species that have been intensively studied are moderately self-compatible, self-fertile, or both. Apparently, complete self-sterility is the exception rather than the rule.

Methods

During the years 1950 through 1953, more than 30 controlled self-pollinations were attempted on 28 different western white pine selections. All were successful in that sound seed was produced in each attempt. Twenty different lots of self-pollinated seed were planted; 6 in 1952, 2 in 1953, and 12 in 1954. Twelve additional lots will be planted in 1955. Records were kept on periodicity of flowering, seed yield, seed germination, and seedling height growth. Seedlings growing in a randomized block design in a nursery at Spokane, Washington, or in outplanting plots in north Idaho or northwestern Montana, were measured for total height after terminal growth ceased in the late fall of 1952, 1953, and 1954. During the 1950 through 1953 pollination years, cross-pollinations (outcrosses) were made between all of the same 28 selections. Similar records on seed and seedling production and seedling growth were kept, and these provided a basis for comparing the effects of self-fertility. Controlled pollinations followed the methods of Cumming and Righter (1948), with minor modifications.

Results and Discussion

Cone, seed, and seedling yields following controlled self- and cross-pollinations. Self-pollination of flowers did not affect cone yield in western white pine. In a comparison of 22 self- and cross-pollinations on the same selections in the same seed years, 71.7 percent of 334 self-pollinated flowers developed into normal cones, and 71.8 percent of cross-pollinated flowers developed into normal cones. Beyond this point in the reproductive cycle, the effects of selfing became apparent (Table 1).

Mean sound seed yield per cone following self-pollination averaged only about 50 percent of that following cross-pollination, and considerable tree-to-tree variation in yield was noted. Similarly, sound seed germinability following self-pollination averaged about 90 percent of that following cross-pollination, also with considerable tree-to-tree variation. The difference in cross- vs. self-pollinated seed germinability (7.3 percent) was not significant, being close to the 10-percent level of probability. Widely different behavior of selfed seed lots from the 1952 pollinations was observed, however, and excluding the 1952 lots, the mean difference in germination (13.2 percent) was significant (close to the 1-percent level). The apparently greater germinability of self- vs. cross-pollinated seed lots from the 1952 pollinations is believed due to failure of the winnowing process to remove partially filled seed from

TABLE 1. Seed yield and germinability in self- vs. cross-pollinations and relative yield of self-pollinated seedlings (western white pine).

Selection No.	Pollination year	Number of crosses (total 107)	Seed yield (Number of seed per cone) Sound seed Self	Sound seed Average cross[2]	Hollow seed Self	Hollow seed Average cross	Seed germinability (per cent)[1] Self	Seed germinability Average cross	Relative yield of self-pollinated seedlings (percent)
1	1952	1	31	54	101	54	29	26	64.0
15	1953	2	75	89	—	—	—	—	—
16	1953	1	21	78	—	—	—	—	—
17	1953	2	100	127	—	—	—	—	—
18	1952	1	7	71	75	1	92	54	16.8
19	1950	16	24	35	—	—	83	84	67.8
20	1950	8	13	89	—	—	62	78	11.6
—	1952	4	89	57	71	22	36	60	93.6
—	1953	7	44	91	—	—	—	—	—
21	1952	1	83	103	28	13	58	50	94.0
22	1950	5	7	117	—	—	77	88	5.2
23	1952	1	43	63	32	14	42	46	61.9
24	1953	1	53	199	—	—	—	—	—
25	1952	1	60	120	83	10	57	88	32.5
27	1953	1	54	121	—	—	—	—	—
30	1950	4	3	56	—	—	76	85	4.8
—	1952	1	19	91	87	49	52	34	32.1
35	1953	1	33	122	—	—	—	—	—
37	1953	2	27	98	—	—	—	—	—
39	1950	2	19	45	—	—	46	82	23.7
45	1953	1	20	68	—	—	—	—	—
54	1951	4	80	106	113	46	17	43	30.0
—	1952	3	102	110	100	38	27	52	48.4
58	1950	11	134	106	—	—	84	87	122.1
59	1952	2	48	123	92	10	68	52	51.1
61	1953	2	19	143	—	—	—	—	—
62	1952	6	63	76	18	17	53	59	74.7
63	1951	4	59	74	29	19	11	15	58.4
64	1953	4	6	56	—	—	—	—	—
65	1953	2	105	173	—	—	—	—	—
69	1952	3	87	84	28	22	69	58	123.8
70	1952	3	56	64	59	17	7	52	11.3
Mean			49.5	94.0	65.4	23.7	52.3	59.6	51.4
Differences				44.5[3]		41.7[3]		7.3	
Percents			52.7	100.0	275.9	100.0	87.8	100.0	

[1]Emergence in seedbeds approximately 100 days after sowing.
[2]Average of all controlled crosses, excluding self, made on the same seed parent in the same pollination year.
[3]Significant at the 1 percent level of probability, determined by paired "t" test.

certain of the cross-pollinated lots. The number of hollow or blind seed per cone following self-pollination averaged over two and three-quarters times that following cross-pollination.

The two variables, self-sound seed yield and seed germinability, together determine the relative yield of self-pollinated seedlings or the "self-ability" of a given selection. Since this could be important information in seed orchard work, it was believed desirable to develop an index, the relative yield of self-pollinated seedlings, expressing the self-ability of each selection. Furthermore, it seemed desirable to have the index comparable between selections. Starting with the premise that yield and germinability following cross-pollination represent

100-percent "cross-ability," then relative self-ability of selections can be expressed by the formula:

$$\frac{\text{No. sound seed per selfed cone}}{\text{No. sound seed per crossed cone}} \times \frac{\text{Percent germinability selfed seed}}{\text{Percent germinability crossed seed}}$$

The resulting index, relative yield of self-pollinated seedlings in percent, is shown for 17 different selections in the last column of Table I. There was great variability in the self-ability of different selections. More complete information based upon repeated trials could be extremely useful in seed production phases of this or similar tree improvement programs.

The variation in self-ability between selections seemed to be due to differences in both self-compatibility and self-fertility. Certain selections like Nos. 58 and 69 appeared to be both highly self-compatible and self-fertile. Others like No. 54 appeared to be highly self-compatible, yet moderately self-infertile. Nos. 1, 19, 21, 62, and 63 appeared to be only moderately self-compatible, but highly self-fertile. Nos. 18 and 22 appeared to be highly self-incompatible but highly self-fertile; still others like 70 appeared to be moderately self-compatible but highly self-infertile. Results following self-pollination of the same selection in different seasons were sometimes roughly similar (selections 30 and 54), sometimes widely different (selection 20). This indicates the necessity for repeating self-pollinations on promising selections.

Apparently the most important barriers to production of self-fertilized seedlings are encountered somewhere in the process of fertilization or embryo development. The greatest part of the decrease in selfed seedling yield resulted from reduced seed production (Table 1). This finding is similar to that of Orr-Ewing (1954) with Douglas-fir.

Most of the features of selfing in western white pine are paralleled in other pines, in Douglas-fir, or in spruce. Langlet (1940) has shown that in comparisons with wind-pollinations, self-pollinations of Norway spruce (*Picea abies* (L.) Karst.) produced seed lower in both germinability and survival. Johnson (1945) reported that Langlet's findings applied equally well to Scotch pine. Righter (1945) showed that selfed Jeffrey pine seed was highly germinable. Allen (1942) found that self-pollinations in Douglas-fir resulted in high apparent seed yields when sound and hollow seed were not separated. Subsequent weighings and germination trials indicated that the selfed lots contained mostly hollow seed. Orr-Ewing (1954) also found total self-pollinated seed yields of Douglas-fir high, but sound seed yield low. Real germination of selfed seed (based on filled seed only) was found to be about the same as that for wind-pollinated seed. Piatnitsky (1934), on the other hand, found that only 1 of 4 self-pollinated larch species (*Larix europaea* D.C.) gave seed lower in germinability than wind-pollinated control seed.

It should be pointed out that selfing under controlled conditions may not result in self-pollinated seed yields strictly comparable to yields following natural wind pollination. In nature, additional barriers to self-fertilization arising from phenological differences, flower position differences, or selective fertilization might be in operation.

The possible phenological barrier, due to different periods of pollen shedding and flower receptivity (dichogamy), was investigated and found nonexistent in the 28 western white pines studied. Periods of pollen shedding and flower receptivity overlapped for from 2 to 10 days with an average of almost 6½ days overlap. This finding is similar to that of Wright (1953) for 14 different species of pine in the Philadelphia, Pennsylvania, area, and to that of Duffield (1950) and Orr-Ewing (1954) for Douglas-fir at Placerville, California, and Vancouver, British Columbia, respectively.

Difference in position of pollen catkins and female flowers in the tree crown, another possible barrier to self-pollination,

was also investigated. It was noted that western white pine pollen was generally borne in the central three-fifths of the live crown, while flowers were borne in the upper two-fifths of the live crown. To what extent this difference in catkin and flower positions is a barrier to self-pollination is difficult to prove. The following observations indicate that it is not always an effective deterrent to selfing. (1) About one-quarter of some 40 selections examined during 4 years of controlled pollination work showed an overlap in the male and female portions of the crown. Overlap was from a few to as many as 30 feet in the average 60-foot-tall selection. (2) It would appear from pollen dispersion studies that in self-compatible trees self-pollination is at least as good a possibility as is cross-pollination, especially in scattered stands. (3) In the nursery, it was noted that wind-pollinated seedling progenies frequently contained a fair proportion of runty seedlings, averaging shorter than seedlings of any of the controlled cross-pollinations made on the same selection with pollens from selections of the same area. Outwardly these runts appeared similar to the dwarfed seedlings developed from self-pollinations (Fig. 1). Selfing is not the only known cause of dwarfing, however, so their origin remains a matter of conjecture. Individual seed weight, not taken into account here, could also affect the validity of this observation, since weight is reflected in seedling size especially during the first few growing seasons (Righter, 1945; Spurr, 1944). Average seed weight was determined for most of the self-pollinated and corresponding cross-pollinated seed lots. In about two-thirds of the cases, seed weight was greater in the selfed lots (Table 2).

Selective fertilization, or the relative efficacy of pollen from a given plant in fertilizing ovules within its own flowers when in competition with pollens from other plants of the same species, might constitute yet another barrier to self-fertilization (Jones, 1928; Piatnitsky, 1947). Selective fertilization in western white pine is under investigation.

Effect of self-fertilization on seedling height. Self-pollinated seedling progenies measured in 1952 (6 progenies), in 1953 (8 progenies), and in 1954 (19 progenies) were mostly smaller than corresponding progenies coming from cross-pollinations made on the same seed trees in the same pollination years (Table 2). Albinism or chlorosis, as noted by A. G. Johnson

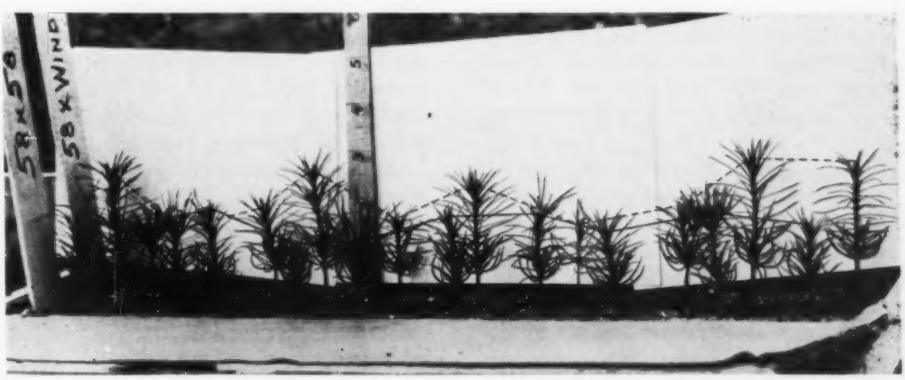

FIGURE 1. Self- and wind-pollinated seedlings of western white pine. Selfed seedlings are the uniformly short seedlings connected by a solid line in the front row; wind-pollinated seedlings, those of irregular height connected by a broken line in the rear row.

TABLE 2. Height growth of self- vs. cross-pollinated seedlings (western white pine).

Selection number	Pollination year	Number of crosses (total 78)	Number of seedlings		Av. height first year (feet)		Av. height second year (feet)		Av. height third year (feet)		Average seed weight (mg.)	
			Self	Average cross[1]	Self	Average cross	Self	Average cross	Self	Average cross	Self	Average cross
1	1952	1	8	9	0.103	0.116	.....	.....	.....	.....	18.4	18.9
18	1952	1	57	40	.134	.144	.....	.....	.....	.....	21.5	21.3
19	1950	16	90	67	.129	.142	0.220	0.270	0.368	0.452	24.9	23.6
20	1950	8	8	56	.118	.151	.202	.283	.289	.455	.....	.....
.....	1952	4	9	20	.124	.130	.....	.....	.....	.....	22.6	24.3
21	1952	1	63	48	.131	.129	.....	.....	.....	.....	23.8	17.4
22	1950	5	25	88	.152	.170	.264	.301	.435	.486	.....	.....
23	1952	1	29	41	.107	.127	.....	.....	.....	.....	24.7	23.8
25	1952	1	50	58	.117	.140	.....	.....	.....	.....	23.9	21.4
30	1950	4	17	76	.138	.159	.262	.315	.427	.513	.....	.....
.....	1952	1	20	15	.132	.121	.....	.....	.....	.....	20.8	21.3
39	1950	2	55	71	.118	.148	.187	.264	.321	.428	.....	.....
54	1951	4	33	64	.077	.111	.137	.191	.....	.....	17.6	15.8
.....	1952	3	13	44	.089	.117	.....	.....	.....	.....	19.5	16.6
58	1950	11	86	84	.133	.161	.242	.307	.406	.504	19.2	17.9
59	1952	2	56	20	.106	.117	.....	.....	.....	.....	17.5	17.6
62	1952	6	19	21	.122	.124	.....	.....	.....	.....	24.6	23.1
63	1951	4	39	38	.086	.093	.138	.161	.....	.....	16.4	16.1
69	1952	3	83	62	.112	.108	.....	.....	.....	.....	16.9	14.1
Mean			40	49	0.1173	0.1320	0.2065	0.2615	0.3743	0.4730	20.82	19.55
Difference					[2]0.0147		[2]0.0550		[2]0.0987		1.27	
Growth rate (percent)					—11.1		—21.0		—20.9			

[1]Average of all controlled crosses, excluding self, made on the same seed parent in the same pollination year.
[2]Significant at the 1-percent level of probability, determined by paired "t" test.

(1948) and L. P. V. Johnson (1945), incomplete growth as noted by Orr-Ewing (1954), or other degenerative effects of inbreeding were not seen.

Table 2 and Fig. 1 demonstrate the extent of height growth depression resulting from selfing in western white pine. In one-year-old seedlings, height growth depression occurred in the selfed progenies of 16 out of 19 selections. It ranged from a few percent to almost 25 percent (average 11 percent). In 2-year seedlings, depression occurred in all 8 selections concerned, ranging from about 13 to 30 percent (average 21 percent). In 3-year seedlings, depression occurred in all 6 selections concerned, ranging from about 10 percent to over 35 percent (average 21 percent).

To some extent, the greater degree of depression noted in 2- and 3-year-old seedlings may be due to progressive suppression of the smaller selfed seedlings growing at 2- by 2-inch spacing when 2-year nursery seedlings. This effect may have carried over in the 1-foot by 1-foot spacing used for 3-year-old seedlings on outplanting plots. Mean height differences of 0.0147, 0.0550, and 0.0987 feet observed for 1-year, 2-year, and 3-year seedlings, respectively, are highly significant even though unadjusted for growing season differences.

Growth depression of self-pollinated seedlings was apparently not a result of average seed weight differences between self and cross seed lots. Average seed weight was measured in 15 of the 19 comparisons, and in 11 of the 15 weighings was greater for the selfed lots. Probably the greater average weight of the selfed lots is partially a result of pollination practice, since the best bagged flowers were often selected for attempting the presumably more difficult self-pollinations.

The depression of growth following self-

ing found in western white pine again parallels the findings of Langlet (1940) for Norway spruce, of Dengler (1932) for Scotch pine, of Johnson (1945) for Scotch and eastern white pines, of Langner (1951) for larch, and of Orr-Ewing (1954) for Douglas-fir.

Conclusions

1. In breeding for blister rust resistance in western white pine, the authors are proceeding on the premise that all selections are to some extent self-compatible and self-fertile. This knowledge also has some practical application.

2. Naturally self-pollinated seedlings may be presumed present in forest tree nurseries, and with other inherently small seedlings could be largely rogued out at transplanting time merely by culling the smallest seedlings.

3. Before embarking on large-scale production of certified tree seed from vegetatively-propagated orchards, it appears that searching tests should be made on self-ability and inbreeding depression for each selection concerned as a possible orchard clone.

4. In seed orchards from grafts or cuttings—the end product of many tree improvement programs—the possibility of natural selfing will be increased by the presence of more than one member of the same clone. Depending on the effects of selective fertilization as discussed above, some system of planting may have to be used which would effectively screen clone members from each other. Langner (1953), Duffield, and other forest geneticists are already working on this problem.

5. Results of progeny trials where only wind-pollinated progenies are under observation should be interpreted with caution, particularly if the species is known to be self-compatible and self-fertile in any degree and if seed parents involved are known to be isolated. There is a strong possibility that naturally-selfed seedlings may occur in such trials and affect the vigor or other rating assigned individual parents.

Summary

The cone and seed yields, and seed germinability following self-pollinations in western white pine were compared with corresponding yields and germinability following cross-pollinations on the same trees. Relative yield of self-pollinated seedlings, an expression of the "self-ability" of individual seed parents, was determined. First-, second-, and third-year seedlings heights of self-pollinated and corresponding cross-pollinated seedlings were compared.

Compared with cross-pollinations, self-pollination cone yields were almost identical. But self-pollination seed yields were 50 percent below cross-pollination yields, hollow seed yields 275 percent above cross-pollination yields, seed germinability 7 to 13 percent below cross-pollinated germinability, and seedling height the first, second, and third years 11, 21, and 21 percent below cross-pollination heights, respectively. The 28 trees tested averaged about 50 percent in "self-ability," i.e., yields of self-pollinated seedlings were about 50 percent those of cross-pollinated seedlings. The range in self-pollinated seedling yield was great, and yield was sometimes inconsistent in successive selfings on the same selection. This indicated the need for repeated tests on important selections.

The 28 western white pines studied appear to constitute a moderately self-compatible, highly self-fertile sample.

Some of the possible natural barriers to selfing seem to be partially or wholly ineffective. Others require additional investigation before they can be evaluated.

Presuming that natural selfing occurs, self-compatibility and self-fertility leading to the production of dwarfed seedlings should be considered in tree improvement work, in nursery practice, in the selection of clones for seed orchards, in the laying out of seed orchards, and in interpreting the results of wind-pollinated progeny performance trials.

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Tree Growth.

I. Some Historical Chapters, by R. A. Studhalter. II. Growth rings and Climate, by Waldo S. Glock. The Botanical Review, Box 749, Lancaster Penn. Volume 21, Numbers 1-3 in one issue. 1955. 188 pp. $1.75.

REVIEW by R. Daubenmire
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THIS RECENT ISSUE of the *The Botanical Review* is essentially a dual monograph of book length (without illustrations) concerned with the significance of growth increments of trees.

The first part is a survey by R. A. Studhalter entitled "Some historical chapters" which is 72 pages in length. Because growth increments could be observed before lenses came into use, these features of plant structure could be studied by the ancients, and because they have held a peculiar fascination for mankind, there is a long historical background which is here presented in detail. This excursion into the philosophical background of our present concepts is interesting in its own right, and it is of further value in comprehending the extent to which current thinking is founded upon a heritage of hypotheses.

W. S. Glock has authored the second part, "Growth rings and climate," which is concerned primarily with the era of interest stimulated largely by the work of A. E. Douglass that began in the early part of this century. This is essentially a revised and somewhat reoriented presentation of subjects discussed under the same title in an earlier number of *The Botanical Review* (7:649-713, 1941). Yet there is vast difference in the source materials so that one who wishes a full review of all the work must consult both articles. Glock's account emphasizes the sharply contrasted outlook of most "dendrochronologists" who are interested in wood layers for their assumed value as indicators of variation in single climatic elements (chiefly precipitation, rarely temperature) as a means of dating climatic, archeologic, or other events of the past millennium, and others who have approached tree growth from a broader ecologic basis. The latter outlook takes into account all environmental factors, without denying that frequently one becomes so critical as to exceed others in importance. The latter approach also takes into account variations in microenvironment, genetics of the individual, fruiting cycles, and especially the troublesome variations in the physiology of different parts of the same tree, as all these conspire to influence the quantity and quality of wood deposition. If one looks for flaws he might be critical of the small use of foreign-language publications, yet it must be conceded that to digest only the work written in English is a tremendous task. Also the organization is such that the same piece of research is referred to repeatedly, sometimes without adding much to the first reference. But in a large measure this reflects the complexity of the subject.

In view of the great volume of literature on topics that have been especially popular with research workers, one can always be thankful for the efforts of a reviewer who brings together a synthesis of a section of it, and in *The Botanical Review* mentioned we have a summary that is of interest and utility to a wide variety of scientists interested in the growth of woody plants.

Deer and Cattle Range Relations in Utah

BY

ODELL JULANDER

DEER AND CATTLE graze together over much of Utah's foothill and mountain rangelands. The mountains provide summer grazing for both, and the foothills are grazed by deer in winter and by cattle chiefly in spring and fall.

Much controversy exists, but factual information is wanting regarding the use of these lands by game and livestock. The studies reported here were made in 1948 to 1952 inclusive to determine the range relations of deer and cattle, and provide a better understanding of the factors affecting management of deer-cattle ranges.

About two-thirds of Utah's deer-livestock range is in Federal ownership and one-fifth is privately owned. Demands are great for grazing both deer and cattle on Federal land. Much of the private land is foothill range, which in many cases is the limiting factor in the production of both deer and livestock. Some overlap in demands between sportsmen and livestock men for use of the land is therefore inevitable. Such land-use competition should be distinguished from forage competition, with which this article is concerned. Forage competition between deer and cattle as referred to here is the conflict for a limited supply of forage which begins with overuse of the important forage species by the two grazing animals.

Previous Work

Few detailed studies dealing with deer-cattle range relations have been made. Julander[1] in 1931–33 recognized competition between deer and cattle, particularly in winter, for key browse species on the depleted Kaibab midwinter range. In 1937, he discussed the principle of key species and key areas in the management of the Kaibab deer-cattle range and gave a palatability rating of forage plants for deer and cattle, listing the plants grazed by each. The Interstate Deer Herd Committee in 1949 recognized direct conflict between deer and cattle in northern California and proposed a plan of deer-cattle management based on proper use of key species on key areas. Julander and Robinette made a preliminary report on part of the present study up to 1950. Kimball and Watkins summarized the deer-cattle forage relations studies on the Kaibab North in 1951. They concluded on the basis of stomach samples that, in general, cattle are grass eaters and deer

A contribution from a cooperative research project conducted by the Utah State Fish & Game Department, U. S. Fish & Wildlife Service, Utah State Agricultural College, and U. S. Forest Service. The author is Range Conservationist at the Intermountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture.

[1]Progress reports on biological and game management studies on the Kaibab National Forest. 1931–1933. Unpublished; in files of Forest Service, Southwestern Region, Albuquerque, N. Mex.

browse eaters. Also "that deer compete little or none with cattle for forage but on the other hand cattle compete materially with deer for forage." Julander in 1952 reported wide variations in competition between deer and livestock in Utah and outlined the factors affecting competition.

Methods of Study

To determine grazing patterns and factors affecting deer and cattle distribution, studies were made on an entire natural deer-cattle unit at Oak Creek on the Fishlake National Forest. Transects were run across the unit approximately at right angles to secondary drainages. Transects were located at random, one in each mile, and were divided into 8-chain segments. Two circular plots, 96 square feet in area, were located at random within each segment, and on these plots weight and utilization of herbage of each species were estimated by the method of Pechanec and Pickford. Using the same points as hubs, deer pellet groups, cow chips, and other signs were recorded on 1/100-acre plots to determine distribution and relative density of the animal population. Aspect, degree of slope, and accessibility were also recorded. The data on animal distribution and density were supplemented by careful observations over the entire unit by W. Leslie Robinette and Jay Gashwiler of the U. S. Fish and Wildlife Service.

Areas of intensive use by deer were delimited for both summer and winter range on the basis of 200 or more pellet groups per acre, or on conspicuous deer sign and heavy use of shrubs (50%+) by deer near the end of the grazing season. Intensive use by cattle was delimited by heavy utilization of grass (50%+), and by numerous cattle tracks and chips.

Forage preference studies were made on the Fishlake, Dixie, Uinta, and Wasatch National Forests wherever deer and cattle grazing could be separated. This was done on permanent cattle exclosure plots and on fenced areas that had been artificially reseeded. Estimates of deer utilization were obtained within cattle exclosures to which deer had access, and of combined deer-cattle utilization on adjacent common-use range. Deer pellet group counts were made inside and out to determine whether relative deer use was comparable on the two areas; if so, the difference in utilization was attributed to cattle. Observations were also made at Oak Creek and other unfenced areas used exclusively by deer and on seasonal range where cattle use could be estimated prior to deer grazing. For each forage species, pounds per acre utilized by deer and by cattle were estimated and from these weights percentage of diets were calculated.

Grazing Patterns

The Oak Creek unit, where grazing-pattern studies were made, covers an area of nearly 49 square miles, extending from the sagebrush valley at approximately 5,300 feet elevation up to the Canyon Mountains divide at about 8,000 feet. The foothill range grazed by deer in winter and by cattle in spring and fall is covered mainly by the juniper type with various mixtures of sagebrush (*Artemisia tridentata*), bitterbrush (*Purshia tridentata*), cliffrose (*Cowania stansburiana*), and minor shrubs. The higher range used for summer deer and cattle grazing is rough, steep terrain covered mainly with various combinations of mountain shrubs, the major species being Gambel oak (*Quercus gambelii*), curlleaf mountain-mahogany (*Cercocarpus ledifolius*), and sagebrush. Conifer and aspen types occur in small patches at higher elevations.

Grazing use and range conditions. Cattle (385 head) graze the deer winter range from May 1 to June 30 and the summer range from July 1 to September 10. Although this is only about one-third of the cattle use permitted in 1921 when serious overgrazing was recognized, the area is still considered overstocked. Deer were reported in small numbers in 1921 but increased rapidly, reaching a peak far in excess of the food supply in 1940–42. Heavy hunting since 1942 has reduced the deer herd to an estimated 2,200 head, which is considered heavy stocking for this area.

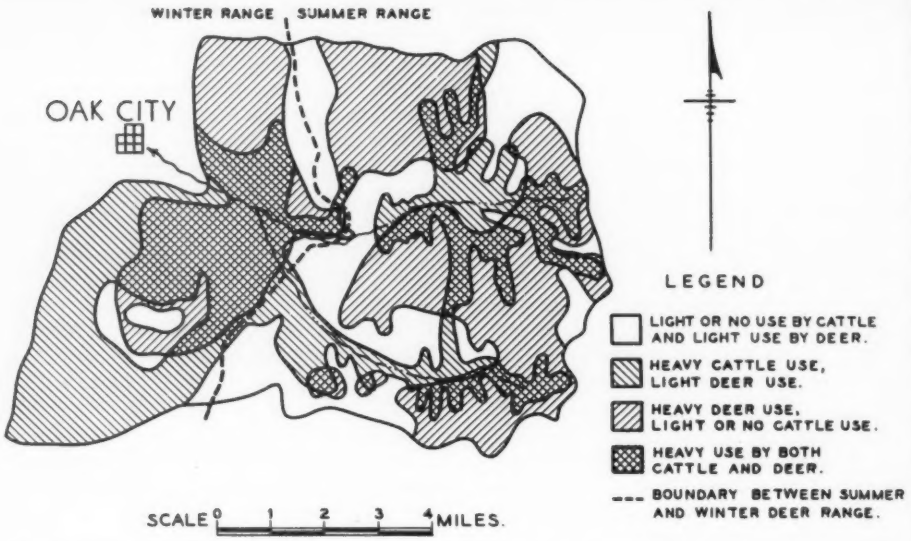
WINTER RANGE
SUMMER RANGE
OAK CITY
LEGEND
LIGHT OR NO USE BY CATTLE AND LIGHT USE BY DEER.
HEAVY CATTLE USE, LIGHT DEER USE.
HEAVY DEER USE, LIGHT OR NO CATTLE USE.
HEAVY USE BY BOTH CATTLE AND DEER.
BOUNDARY BETWEEN SUMMER AND WINTER DEER RANGE.
SCALE 0 1 2 3 4 MILES.

FIGURE 1.—Distribution of deer and cattle grazing on Oak Creek range, west-central Utah, 1951.

Deer and cattle numbers have been held fairly constant since 1948.

Areas accessible to cattle over the entire unit were reported severely depleted by cattle in 1921 when the deer population was still very low. Since then, large numbers of deer have no doubt contributed to the further depletion of this range. Much of the area inaccessible to cattle has also suffered from overstocking of deer.

Even with past heavy reductions in deer and cattle, the areas readily accessible to cattle and areas of deer concentration on both summer and winter ranges are at present very heavily grazed. Reduction in cattle numbers resulted in decreased use of steep, rough areas, but canyon bottoms of the summer range are still grazed severely. While this situation is not uncommon in Utah, the Oak Creek unit is not typical of good cattle range, and the desirability of grazing cattle on such range is seriously questioned by range administrators.

Animal distribution and key areas. In general both deer and cattle concentrate on areas of choice forage if they can get to them. The most favorable plant environments, such as the coves of side canyons, gentle swales, and plateaus with better soils producing the greatest variety and abundance of plants, are attractive to deer and cattle alike, and therefore the two often prefer the same feedgrounds.

Figure 1 shows the areas of concentrated deer and cattle use on the Oak Creek unit and the overlap in intensive use under present stocking. Deer grazed over the entire area except the very ledgy parts, and grazed about three-fifths of the summer range intensively. Cattle grazed approximately half of the summer range, but chiefly because of the rough, steep topography, they used only about one-third of it heavily. Only 20 percent was grazed intensively by both deer and cattle. Winter range was more accessible to cattle and they grazed nearly three-fourths of it intensively, while deer made heavy use of slightly over half. About one-third of the winter range was used intensively by both deer and cattle.

Areas grazed intensively by cattle only and by deer only may serve as key areas to be used as guides in determining the rela-

tive numbers of each that the range will support. It is on the areas of dual intensive use of summer and winter range, however, that deer and cattle compete most severely for forage. *These are the areas upon which management for combined deer-cattle use should be based.*

The little-used areas shown blank in Figure 1 are largely rough, steep slopes with poor forage. Lack of suitable forage was the chief factor limiting deer distribution of such areas. Exposure and protective cover also appeared to have some effect on deer distribution on winter range. Some intermediate range near the seasonal boundary line was used by deer mainly in moving from summer to winter range and returning. This area received only light deer use even though good forage was present. Steep, rough topography limited or completely excluded cattle use on large areas of summer range. They grazed chiefly along canyon bottoms, swales, and gentle slopes. Lack of water during the permitted grazing season prevented cattle from using the north end of the deer winter range. Factors affecting deer and cattle distribution have been described by Julander (1953) and by Julander and Robinette (1950).

Forage Preferences

Summer range. The results of forage preference studies on four very important deer-cattle summer-range types are given in Table 1. Four aspen-forb, five aspen-browse, one oak, and two mountain brush areas were studied in various parts of Utah. The study areas varied in range condition from good to poor.

During summer, grass made up a negligible part of the deer diet in all types regardless of the amount available. Forbs and browse made up most of the deer summer diet; the proportions of each varied widely depending on the kind and amount of forage present. Where palatable forbs were plentiful, they made up a high percentage of the deer diet regardless of what other forage was available. Where the better browse species were plentiful, they made up a large share of the diet. The proportion of browse was particularly high where forbs were scarce, as in the mountain brush type.

Grass was a preferred forage for cattle in all types and made up a large part of their diet wherever available. Some forbs and browse were utilized by cattle, however, even where grass was plentiful, as shown for the aspen-forb and aspen-browse types in Table 1. On the oak and mountain brush types, where grass had been depleted by overgrazing, cattle fed mainly on forbs and browse, and their diet was similar to that of deer. In the oak type at Oak Creek, which is seriously overgrazed and heavily stocked with both deer and cattle, the two animals were forced to eat the same plants. Forage competition here was severe, whereas in the two aspen types where grass was more plentiful, cattle fed largely on grass and deer on forbs and browse so that forage competition was much less.

A striking example of the effect of range condition and overstocking is shown by two extreme cases. On the depleted, overstocked oak type, the species that made up 92 percent of the cattle diet accounted for 99 percent of the deer diet. (Table 1). In contrast, on one of the five aspen-browse areas representing good range condition and moderately stocked with both deer and cattle, species that made up 100 percent of the cattle diet comprised only 10 percent of the deer diet. A more typical case of forage preference overlap is represented by weighted averages of the nine aspen areas studied. The ten most palatable deer forage species here made up 75 percent of the deer diet and 29 percent of the cattle diet.

Utilization of the desirable species (percent use column under each type in Table 1) reflects the intensity of combined deer-cattle use and indicates the relative summer forage preferences for each species. Several forbs stand out as preferred forage plants for deer wherever they occur: Paintedcups (*Castilleja linariaefolia, C. sulphurea*), asters (*Aster engelmannii, A. denudatus,* and *A. chilensis*), and showy goldeneye (*Viguiera multiflora*). Lupines (*Lupinus alpestris, L. kingii, L. spathulatus,* and other

TABLE 1. Forage use by deer and cattle on Utah summer range, 1947-52. Diet figures are percentages of total forage consumed as determined by weight-utilization estimates. Volume of herbage estimated in pounds per acre, green weight.

Species	Aspen-forb[1]				Aspen-browse[2]				Oak[3]				Mountain brush[4]			
	Lbs./A.	Percent Use	Percent of diet Deer	Percent of diet Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Percent of diet Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Percent of diet Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Percent of diet Cattle
All grasses	215	23	tr.	86	310	33	2	76	11	85	1	8	45	67	2	36
Forbs:																
Hydrophyllum capitatum	....	....	....	....	....	....	....	....	185	45	23	62	....	....	....	....
Trifolium rydbergii	....	....	....	....	....	....	....	....	....	....	....	....	3	80	3	1
Lupinus alpestris, others	156	21	46	1	....	....	....	....	....	....	....	....	1	67	1	1
Achillea lanulosa	11	18	2	1	2	10	tr.	tr.	7	25	2	1	....	....	....	....
Astragalus straturensis	14	59	8	5	....	....	....	....	....	....	....	....	....	....	....	....
Taraxacum officinale	9	18	2	tr.	1	20	tr.	tr.	13	75	7	6	....	....	....	....
Castilleja spp.	1	60	1	1	2	70	1	1	....	....	....	....	3	60	3	1
Aster spp.	14	49	7	3	12	51	3	3	....	....	....	....	5	50	2	1
Viguiera multiflora	4	35	1	1	7	29	2	tr.	....	....	....	....	7	33	3	2
Geranium richardsonii	....	....	....	....	26	39	10	1	....	....	....	....	....	....	....	....
Pseudocymopterus montanus	5	58	4	tr.	....	....	....	....	....	....	....	....	....	....	....	....
Thalictrum fendleri	1	....	0	0	17	15	3	tr.	....	....	....	....	....	....	....	....
Vicia americana	....	....	....	....	34	10	2	1	4	85	4	1	1	33	1	tr.
Fragaria bracteosa	9	38	5	0	1	tr.	0	0	....	....	....	....	....	....	....	....
Miscellaneous forbs	26	33	10	tr.	94	15	9	4	38	40	30	3	9	10	tr.	1
All forbs	250		86	12	196		30	10	247		66	73	29		13	7
Browse:																
Populus tremuloides	13	53	11	2	12	5	1	tr.	....	....	....	....	....	....	....	....
Prunus virginiana	....	....	....	....	26	23	6	1	3	70	3	1	....	....	....	....
Symphoricarpos oreophilus	15	5	tr.	tr.	89	3	1	1	2	20	1	tr.	5	tr.	tr.	tr.
Amelanchier alnifolia	....	....	....	....	40	30	8	3	8	80	8	3	72	32	33	12
Purshia tridentata	....	....	....	....	72	60	41	3	....	....	....	....	38	71	18	24
Chrysothamnus viscidiflorus lanceolatus	....	....	....	....	17	29	0	4	....	....	....	....	....	....	....	....
Physocarpus and *Rosa* spp.	....	....	....	....	26	35	7	2	....	....	....	....	....	....	....	....
Cercocarpus ledifolius	....	....	....	....	....	....	....	....	....	....	....	....	50	10	tr.	6
Artemisia tridentata	....	....	....	....	123	0	0	0	15	0	0	0	248	0	0	0
Quercus gambelii	....	....	....	....	....	....	....	....	40	55	15	13	209	21	31	15
Others	7	14	3	tr.	85	3	4	tr.	10	50	6	2	27	13	3	tr.
All browse species	35		14	2	490		68	14	78		33	19	649		85	57
TOTALS	500		100	100	996		100	100	336		100	100	723		100	100

[1]Aspen-forb type: Heavy use by deer; light to moderate use by cattle. 4 areas studied.
[2]Aspen-browse type: Heavy use by deer; light to heavy use by cattle. 5 areas studied.
[3]Oak type: Heavy use by both deer and cattle. 1 area studied.
[4]Mountain brush type: Light use by deer; heavy use by cattle. 2 areas studied.

species), are all important forage for deer on summer range in late summer and fall. Species of browse which stand out as preferred deer summer forage are bitterbrush, serviceberry (*Amelanchier alnifolia*) and chokeberry (*Prunus virginiana*).

From other studies not included in Table 1 and from previous work (J. G. Smith, 1952), the following forbs and browse have also been classed as highly-preferred summer deer forage wherever they occur: Clover (*Trifolium rydbergii*), loveroot

TABLE 2. Forage use by deer and cattle on Utah deer winter range, 1947-52. Diet figures are percentages of total forage consumed as determined by weight and utilization estimates. Volume of herbage estimated in pounds per acre, green weight.

Species	Juniper-sagebrush-cliffrose[1]				Juniper-sagebrush-bitterbrush[2]				Oak-sagebrush-grass[3]				Pinyon-sagebrush-bitterbrush[4]			
	Lbs./A.	Percent Use	Percent of diet Deer	Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Cattle	Lbs./A.	Percent Use	Percent of diet Deer	Cattle
Grasses:																
Bromus tectorum	50	35	tr.	31	30	10		17	----	----	----	----	----	----	----	----
Perennial grasses	38	62	tr.	39	37	10	1	8	136	40	4	58	7	82	2	9
All grasses	88		1	70	67		1	25	136		4	58	7		2	9
Forbs:																
Lupinus spp.	----	----	----	----	----	----	----	----	88	5	1	2	10	66	7	7
Lotus wrightii	----	----	----	----	----	----	----	----	----	----	----	----	2	69	2	2
Chaenactis douglasii	----	----	----	----	----	----	----	----	----	----	----	----	4	50	3	1
Balsamorhiza sagittata	----	----	----	----	----	----	----	----	136	14	8	6	----	----	----	----
Viguiera multiflora	----	----	----	----	----	----	----	----	48	17	1	8	----	----	----	----
Castilleja linariaefolia	----	----	----	----	----	----	----	----	12	3	1	1	----	----	----	----
Aster chilensis	----	----	----	----	----	----	----	----	19	26	1	4	----	----	----	----
Wyethia amplexicaulis	----	----	----	----	----	----	----	----	50	8	2	0	----	----	----	----
Miscellaneous forbs	5	30	1	2	9	10	tr.	6	59	8	2	tr.	14	15	tr.	tr.
All forbs	5		1	2	9		tr.	6	412		16	21	30		12	10
Browse:																
Artemisia tridentata	150	13	26	0	543	21	63	0	251	22	31	0	402	tr.	tr.	0
Cowania stansburiana	103	38	51	0	----	----	----	----	----	----	----	----	----	----	----	----
Purshia tridentata	43	62	14	28	217	32	33	69	34	74	8	13	70	59	79	13
Amelanchier alnifolia	----	----	----	----	3	20	tr.	tr.	40	18	3	1	4	74	5	2
Quercus gambelii	----	----	----	----	150	2	2	0	210	25	29	1	169	17	tr.	54
Cercocarpus ledifolius	----	----	----	----	3	42	1	0	----	----	----	----	10	65	2	11
Cercocarpus montanus	----	----	----	----	----	----	----	----	11	73	4	2	----	----	----	----
Chrysothamnus viscidiflorus	19	1	tr.	tr.	----	----	----	----	26	35	3	4	1	75	0	1
Juniperus osteosperma	994	tr.	6	0	783	tr.	tr.	0	----	----	----	----	----	----	----	----
Pinus edulis	----	----	----	----	----	----	----	----	----	----	----	----	150	0	0	0
Miscellaneous shrubs	14	tr.	1	0	19	tr.	tr.	0	87	5	2	0	4	tr.	tr.	tr.
All shrubs	1,323		98	28	1,718		99	69	659		80	21	810		86	81
TOTALS	1,416		100	100	1,794		100	100	1,207		100	100	847		100	100

[1]Juniper-sagebrush-cliffrose type: Heavy winter use by deer; heavy spring use by cattle. 2 areas studied.
[2]Juniper-sagebrush-bitterbrush type: Moderate winter use by deer; light spring use by cattle. 1 area studied.
[3]Oak-sagebrush-grass type: Heavy winter use by deer; moderate fall use by cattle. 2 areas studied.
[4]Pinyon-sagebrush-bitterbrush type: Moderate winter use by deer; very heavy summer use by cattle. 1 area studied.

(*Ligusticum porteri*), tall larkspur (*Delphinium barbeyi* and others), valerian (*Valeriana edulis* and *V. occidentalis*), geranium (*Geranium richardsonii*), elderberry (*Sambucus glauca* and *S. microbotrys*), the mountain-mahoganies (*Cercocarpus montanus* and *C. ledifolius*), myrtle pachistima (*Pachistima myrsinites*), ninebark (*Physocarpus malvaceus*), and wildrose (*Rosa* spp.). Deer tend to browse some of these shrubs chiefly in late summer and autumn on summer range. This is particularly true of curlleaf mountain-mahogany.

The forbs and browse species mentioned are likely to be key species for deer on summer range. Grasses are preferred forage for cattle and are usually selected as their key forage species. Cattle also utilize most

of the choice deer forages listed above, however, and where the supply is insufficient for both deer and cattle, there is likely to be competition for these choice species. Table 1 shows several of these forbs and shrubs utilized more heavliy than the grasses as a class, and this was also true for individual species under combined use of deer and cattle. Therefore, forbs and shrubs should be considered in selecting key species for the management of deer-cattle ranges.

Aspen and Gambel oak are important deer forages on many overgrazed ranges, particularly where forbs and other browse are scarce. They also furnish considerable cattle forage where the more preferred forage is lacking; for example, in Table 1 notice the use of oak in the oak and mountain brush types. These two plants, however, are not usually as highly preferred by either deer or cattle as the species listed above. Snowberry (*Symphoricarpos oreophilus*) is utilized but little except under heavy stocking, and big sagebrush is seldom browsed in summer.

Deer winter range. Results of forage preference studies on four important types grazed by deer in winter and by cattle at other seasons are given in Table 2. The juniper-sagebrush-cliffrose and juniper-sagebrush-bitterbrush types are on the Oak Creek study unit; the oak-sagebrush-grass types are on the Wasatch National Forest in northeastern Utah; and the pinyon-sagebrush-bitterbrush type is on the Dixie National Forest of southern Utah.

The percent-diet columns in Table 2 show that deer depended largely on browse for winter forage. Twenty percent or less of the deer diet on winter range was forbs and grass, and most of this was consumed in early spring just before deer migrated to summer range.

Grass was one of the preferred forages for cattle on deer winter range regardless of season of use, and it made up a substantial part of their diet wherever it was present in quantity. The more palatable shrubs were browsed by cattle, and in the overgrazed pinyon-sagebrush-bitterbrush type where little else was available, shrubs formed the major part of the cattle diet. In the juniper-sagebrush-bitterbrush type, bitterbrush formed a large share of the cattle spring diet. Here perennial grasses were widely scattered and bitterbrush was more readily available. Even with a relatively good supply of grass, as in the oak-sagebrush-grass types, browse made up 21 percent of the fall diet of cattle. Where palatable forbs are plentiful, they may make up a substantial part of the diet of cattle: in the oak-sagebrush-grass type they formed 21 percent of the cattle diet in the fall.

From the data in Table 2 and numerous observations on other areas, three browse species stand out as choice winter deer forage: Bitterbrush, true mountain-mahogany (*Cercocarpus montanus*), and curlleaf mountain-mahogany. Observations near Kamas in north-central Utah show they were preferred over other species and were utilized about equally by deer in winter.

Smith and Hubbard (1954), working with deer in captivity, list hybrid mountain-mahogany, curlleaf mountain-mahogany, cliffrose, and bitterbrush as winter deer forage plants that are both preferred and highly productive of easily available forage. True mountain-mahogany is rated a class lower.

Bitterbrush and true mountain-mahogany are top-ranking shrubs for cattle as well as for deer. With one exception (in the pinyon-sagebrush-bitterbrush type where grass is scarce and cattle use heavy) percentage utilization of these two shrubs is greater than that of perennial grasses (Table 2). On the oak-sagebrush-grass type with only moderate fall cattle-grazing and a good supply of grass, cattle utilized bitterbrush and true mountain-mahogany about 25 percent before deer moved to the winter range. These two shrubs are likely to be key forage species for combined deer-cattle grazing on deer winter ranges of Utah wherever they form an important part of the vegetation.

Curlleaf mountain-mahogany is likely to be a key forage species for deer on winter range, but it is usually not browsed by cattle except when more palatable forage is

scarce, as in the pinyon-sagebrush-bitterbrush type. Cliffrose likewise is sometimes a key winter forage species for deer. Cattle grazing in winter are likely to compete with deer for this shrub. Cattle graze most of the cliffrose range in Utah primarily in spring and fall, however, and at these seasons they browse very little on cliffrose.

Sagebrush is the most abundant browse on deer winter ranges in Utah. It is grazed throughout the winter and, although it is ordinarily utilized rather lightly compared to the shrubs listed above, it supplies a large volume of winter forage for deer. Sagebrush was not used by cattle during spring, fall, or summer on the areas studied (Table 2). Utah juniper (*Juniperus osteosperma*), which showed no use by cattle and only little use by deer, is very important over most of Utah as winter cover for deer. It regularly makes up a small part of the deer winter diet but is considered especially important in supplying emergency deer forage during periods of deep snow and severe weather. Pinyon pine (*Pinus edulis*), although less desirable than juniper as forage, serves in a similar capacity.

Utilization of grasses shown in Table 2 is attributed chiefly to cattle. However, some species, especially the bluegrasses (*Poa fendleriana, P. longiligula,* and others) start growth early and are important deer forage on winter range for a short period in early spring.

Forbs are likewise important deer forage for a short period in the spring. All forbs observed were utilized to some extent by deer. Most of the same species were grazed to some extent by cattle. However, forbs are not of outstanding importance on deer winter range, because of their scarcity and their short season of use.

Discussion

All the data presented indicate that, because of differences in forage habits, the ranges studied can be more efficiently utilized by grazing both deer and cattle than by grazing either one alone. The study also indicates that wherever there is joint use, grazing by deer and by cattle must be correlated in order to prevent or correct conflict for forage.

Competition between deer and cattle depends upon the extent of overlap of the areas grazed and on the forage preferences and supply of preferred forage in relation to number of grazing animals. If forage is plentiful, the animals are essentially not in competition for it. But as soon as overutilization of the important species begins, forage competition begins, and this affects management of the range.

Several factors, which vary with the character of each range, affect forage competition between deer and cattle (Julander and Robinette, 1950). Factors that influence deer and cattle distribution and overlap of intensively grazed areas are: (1) Steepness and roughness of slope, (2) water supply, (3) range type and forage composition, and (4) management practices. Factors that affect overlap in forage utilization by deer and cattle are: (1) Natural forage preferences, (2) intensity of stocking, (3) range condition and forage composition, and (4) season of use. On the summer range areas studied, degree of overstocking appeared to be the most important factor affecting forage competition. The same is probably true for winter range, although the data presented are not appropriate to establish this point.

Several of the factors listed affect the utility of a range for deer and cattle and should be considered in allocating deer and cattle grazing. In the Oak Creek unit, for example, much of the choice cattle forage has been depleted by over-use, large areas of summer range have slopes too steep for use by cattle but are used by deer, and a large percentage of winter range herbage (notably cliffrose and sagebrush) is unpalatable to cattle but is eaten by deer. Hence this range is better suited to deer than to cattle and can support a large population of deer with relatively little interference with cattle grazing. This is less so on several other areas studied.

To determine exchange grazing capacity between deer and cattle is difficult because of the interaction of the several factors

listed above. For example, if all cattle were removed from one of the ranges studied, more of the choice forage would be available for deer, but changes in deer diet would probably occur with an increase in available forage. Other factors such as accessibility of the additional forage and changes in animal distribution may also complicate the problem of evaluating competition in terms of grazing capacity. In any case, exchange grazing capacity would have to be worked out for each individual allotment.

Despite such difficulties of determining competition between grazing animals, the balancing of total grazing numbers with available forage is of paramount importance in stabilizing soil and producing maximum sustained yields of forage. Although the data presented here cannot be applied directly to ranges in general, they provide a guide to the determination of key areas for deer and cattle and key species as bases for management of a range.

On the Oak Creek unit, for example, the cross-hatched areas (Fig. 1) are the key areas for combined deer-cattle use. Management should be guided by safe utilization on these areas supplemented by utilization on areas grazed heavily by deer only and cattle only. Studies on this unit (Julander and Robinette, 1950) show that on summer range, maximum cattle stocking should be limited by moderate use of perennial grasses; maximum deer stocking should be based on moderate use of curlleaf mountain-mahogany, true mountain-mahogany, and palatable forbs; and maximum combined deer-cattle stocking should be based on moderate use of forbs and true mountain-mahogany. Likewise, on Oak Creek winter range, proper use of perennial grasses limits maximum sustained cattle grazing; proper use of bitterbrush limits maximum deer stocking; and since bitterbrush is palatable to both, its safe use is the limiting factor for combined deer-cattle grazing.

The principles illustrated for Oak Creek apply to all of the other areas studied, namely that: (a) *Proper use of perennial grasses limits maximum cattle stocking*, (b) *proper use of forbs and browse palatable to deer limits maximum deer stocking*, and (c) *proper use of forbs and browse palatable to both kinds of animals limits maximum combined deer-cattle stocking*. This is true because grass is the first forage to be fully utilized with exclusive cattle grazing; with exclusive deer grazing, their choice forb and browse species are the first to reach the point of proper use; and when combined maximum deer-cattle grazing is permitted, full use is first reached by those species of forbs and browse palatable to both.

Exceptions will probably occur, particularly where species of browse and forbs relished by cattle are absent. For example, on a juniper-sagebrush-cliffrose-grass range grazed by deer in winter and cattle in spring and fall there would be very little overlap in forage preferences. Here cattle stocking could be based on utilization of grasses and deer stocking on utilization of browse. If adjustments in grazing numbers are necessary in this case, the degree of use of the different classes of forage may dictate the necessary changes in deer, cattle, or both. Maximum combined deer-cattle stocking, however, may not always be the most desirable from a social and economic standpoint. Certain areas may be reserved strictly for big-game use because of high demands for the recreational values of big game. In other cases, the range is privately owned and the owner may be interested only in cattle grazing .

Although the most severe competition for forage occurs on areas used intensively by both deer and cattle, conflict is not limited to such areas. For instance, if the important forage plants palatable to both deer and cattle are utilized 15 percent by deer and an additional 60 percent by cattle, the combined utilization equals 75 percent. If 60 percent is proper utilization for these species, then the range is 15 percent overutilized and deer and cattle are competing for forage to that extent. To ignore relatively sparse big-game populations, such as often occur on Utah summer ranges, in determining numbers of livestock to graze,

may result in over use of the range. Hence the combined impact of all grazing animals must be considered in determining grazing capacity.

Summary

Studies were made at Oak Creek deer-cattle range in Utah to determine grazing patterns of deer and cattle. Forage preference studies were made here and on other deer-cattle ranges throughout Utah.

Forage competition between deer and cattle ranged from very light to severe on the areas studied.

On the Oak Creek range, deer utilized large areas of good forage that were inaccessible to cattle. Suitable forage was the major factor affecting deer distribution on summer range, whereas desirable forage, exposure, and cover determined deer distribution in midwinter. Cattle distribution was influenced mainly by steepness of slope and availability of water and forage. The cattle grazed chiefly along canyon bottoms and the gentle slopes.

About a fifth of the Oak Creek summer range and a third of the winter range were used heavily by both deer and cattle. Management of this deer-cattle range should be based on proper utilization of forage on these areas, where competition for forage is most severe.

Forbs and browse accounted for most of the summer deer diet. In summer cattle fed mainly on grass if it was available; otherwise they fed largely on browse and forbs. Most of the choice deer forage species were utilized to some extent by cattle, but grass, the choice cattle forage, formed a negligible part of the deer diet in summer.

Browse formed most of the deer diet on deer winter range. The more palatable species are bitterbrush, curlleaf mountain-mahogany, true mountain-mahogany, and cliffrose. Bitterbrush and true mountain-mahogany were also palatable to cattle in spring and fall. Curlleaf mountain-mahogany, cliffrose, and sagebrush were used little by cattle in spring and fall. Grasses were used heavily by deer only in early spring.

On the areas studied, maximum sustained grazing use is limited by (a) proper use of perennial grasses for exclusive cattle grazing, (b) proper use of palatable shrubs and forbs for exclusive deer grazing, and (c) proper use of shrubs and forbs palatable to both kinds of animals for maximum combined deer-cattle grazing.

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Construction of an Aerial Stand Volume Table for Upland Oak

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TIMBER VOLUME may be determined from aerial photographs by two basically different methods. In the first method, the volumes of single trees are obtained from aerial tree volume tables by photogrammetric measurement of tree height and crown diameter. Such aerial tree volume tables have been constructed by conversion and adaptation of ordinary volume tables or by directly correlating individual tree volumes with photo measurements of crown diameter and height (Ferree, 1953). In the second method, the volume of a stand or plot is directly estimated from aerial stand volume tables. The required photo measurements are stand characteristics such as stand height, stand density, and average crown diameter. It should be evident that the use of stand volume tables is a great deal simpler than the use of tree volume tables if stand volume is the statistic desired.

According to Spurr (1952), the first studies regarding the direct estimation of stand volume from aerial photographs were made in Germany from 1925 to 1933. Wilson, Seely, and Andrews pioneered the work in Canada, making volume estimates from aerial photographs on a practical scale, frequently using crude stand volume tables based on height and sometimes also on density. Stand volume tables based on height alone were prepared by Spurr (1946) for white pine and loblolly pine. Douglas-fir stand volume tables based on height and crown closure have been published by Pope (1950). Moessner, Brunson, and Jensen (1951) have constructed an aerial stand volume table for the central hardwood region, expressing stand volume in terms of stand height, average crown diameter, and crown-cover percent.

Little information is as yet available on methods for the construction of aerial stand volume tables. Likewise, the accuracy of stand volume tables and the limitations inherent in the application of such tables have not been fully investigated. The present paper deals mainly with problems encountered in the course of constructing an aerial stand volume table for upland oak in central Pennsylvania.

Field Data and Photo-measurements

A total of 93 one-fifth acre plots were randomly located on 1:12,000-scale photographs of upland oak stands in Centre County, Pennsylvania. The photographs were taken on infrared film with a minus-blue filter. Contact prints were made on semi-matte paper. The selected plots showed a wide range of volume, stand height, and density. After making an accurate scale determination of the photo-

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graphs in the neighborhood of the selected plots, each plot center was located on the ground as accurately as possible with the help of chain and compass. A two-man crew measured the diameter at breast height of every tree five inches and larger. The gross cubic-foot volume of each plot was then determined on the basis of an established average local volume table, and the volume was also calculated for the trees larger than 7 inches in diameter. These calculated volumes included all trees on the plot above the specified minimum size, whether or not they could be seen on the aerial photograph. In the establishment of an aerial stand volume table it is as easy to correlate total volume, as to correlate seen volume, with height and other stand characteristics. Aerial tree volume tables, on the other hand, only permit the direct determination of seen volume. Additional ground measurements made on each plot included the actual height of the dominant and codominant trees, average crown diameter, average estimated visible crown diameter, merchantable height, and form class. Not all of these measurements have been used in this investigation.

The photo-measurements made for each plot include height, crown diameter, relative crown cover and number of visible trees. The accuracy of the first three of these photo-measurements has been investigated, considering both the non-compensating systematic errors and the unavoidable accidental errors of measurements (Worley and Landis, 1954; Worley and Meyer, 1955). The significance of these errors is briefly indicated in the last section of this paper. The tree count data obtained from the photographs were correlated with the number of trees actually counted on the ground. The result was very discouraging. The poor correlation between the tree number on the photographs and the actual tree number is probably due to the presence of multiple stem trees and interlocking crowns. In stands of conifers, tree counts on photograhps would undoubtedly give more promising results. In the present investigation, which deals exclusively with mixed hardwood stands, the variable number of trees per plot was given no further consideration.

As indicated above, the photo-measurements which can be successfully correlated with stand or plot volume are tree height, crown diameter, and relative crown cover expressed as a percentage. Tree height and crown diameter measurements refer to individual trees. Averages of two or more trees may be formed to obtain a value characteristic for the plot as a whole. The various stand characteristics are here defined as follows:

Stand height is the average height of the three tallest trees on the plot. Other expressions for stand height were investigated, but it was found that the correlation between plot volume and the average height of the three tallest trees was somewhat higher than between plot volume and, for example, the single tallest tree. Attempts were also made to measure the average stand height considering chiefly the dominant and codominant trees, but the correlations were lower, undoubtedly because a considerable amount of subjective judgement is introduced when the average height of the plot as a whole is estimated.

The heights used for the establishment of the aerial stand volume table are the actual heights of the three tallest trees measured on the ground. The use of actual height eliminated the inclusion of systematic errors of height measurements made on the photographs; errors which are known to differ for various observers and observer-instrument combinations. A photo-interpreter using photo-height to determine stand volume should make the necessary adjustments for the particular bias of his measurements (Worley and Landis, 1954).

Crown diameter is defined as the average crown diameter of the trees having the three largest crowns. These three trees do not necessarily coincide with the three tallest trees. The averages of two photo measurements were used. Because of the interlocking of crowns, particularly of multi-stem sprouts, and because of shad-

ows obscuring parts of crowns, ground measurements of crown diameter bear little relation to the crowns actually distinguished on photographs. The photo measurements made with the micrometer wedge proved to be accurately reproducable, the standard error of a single measurement being equal to ± 3.7 feet (Worley and Meyer, 1955). An average of six measurements (3 trees each measured twice) is, therefore, affected by a standard error of less than 2 feet.

TABLE 1. Basic data for aerial stand volume table.

Plot No.	Volume per plot		Stand height	Crown diameter	Crown cover	Plot No.	Volume per plot		Stand height	Crown diameter	Crown cover
	Y	Y′	X_1	X_2	X_3		Y	Y′	X_1	X_2	X_3
	cu. ft.	cu. ft.	feet	feet	per cent		cu. ft.	cu. ft.	feet	feet	per cent
1	460	460	90	33	84	51	704	654	90	19	62
2	433	354	74	26	58	52	704	700	90	22	75
3	365	357	70	29	68	53	387	316	72	18	73
4	376	235	75	26	88	54	295	253	90	26	76
5	419	386	68	30	88	55	350	300	82	23	65
6	330	118	58	24	87	56	585	573	88	25	69
7	362	345	80	29	48	57	690	686	104	31	90
8	381	352	87	31	53	58	864	864	90	31	82
9	431	402	80	28	72	59	991	991	110	31	83
10	1038	1013	120	28	88	60	534	492	82	18	86
11	482	407	72	23	96	61	485	448	76	23	66
12	322	239	60	24	59	62	729	721	82	19	80
13	379	325	72	24	77	63	501	497	85	19	67
14	381	369	72	30	62	64	430	430	104	27	69
15	526	509	80	21	86	65	736	736	110	32	75
16	466	454	80	32	84	66	797	797	95	38	83
17	558	508	90	19	78	67	679	679	112	34	81
18	281	81	55	20	85	68	715	715	107	42	88
19	335	198	60	27	72	69	549	545	112	30	68
20	329	175	58	19	92	70	630	630	105	33	68
21	433	379	90	24	85	71	371	338	70	25	49
22	508	458	85	22	93	72	445	420	76	30	66
23	521	471	74	18	94	73	173	94	42	24	61
24	655	655	110	31	72	74	209	167	65	17	83
25	531	519	86	23	73	75	91	20	47	14	90
26	426	293	65	18	88	76	197	193	65	21	44
27	424	341	80	28	83	77	20	8	51	29	29
28	325	308	90	30	71	78	127	40	55	18	58
29	405	305	75	25	72	79	33	0	38	20	50
30	427	406	80	36	72	80	219	111	57	14	97
31	341	283	72	26	87	81	471	463	110	29	54
32	411	386	80	25	83	82	280	114	64	14	95
33	366	266	70	15	86	83	188	96	46	18	63
34	528	461	71	31	54	84	207	165	43	25	47
35	546	517	90	28	76	85	382	336	72	31	60
36	444	415	87	18	86	86	256	206	64	22	68
37	436	411	90	22	89	87	253	186	60	29	53
38	430	405	90	22	84	88	216	149	63	14	72
39	582	570	80	33	65	89	172	151	50	19	88
40	471	396	77	27	84	90	187	129	64	25	55
41	503	491	100	30	68	91	166	79	52	18	78
42	533	525	108	34	72	92	131	106	46	21	88
43	322	239	74	19	92	93	153	116	58	18	74
44	610	593	96	25	80						
45	860	852	110	35	83						
46	964	956	120	24	79						
47	425	375	75	22	68						
48	230	193	74	34	55						
49	265	253	65	34	65						
50	429	387	80	27	81						

Relative crown cover was determined separately for each plot and not for the stand as a whole. Two devices are available for measuring crown-cover percent, the dot grid and the crown density scale. An investigation of their relative accuracy indicated that the dot grid method is somewhat superior to the application of a crown density scale (for description of method see Worley and Meyer, 1955). The accidental error of individual measurements is about 10 percent for both methods, but the individual systematic error which may amount to as much as 5 to 10 percent is slightly smaller for the dot grid method. Since, however, the crown density scales are more easily applied and are in general use by foresters (Moessner, 1949), the averages of six measurements made by three different observers using the crown density scale were used in this study. Tests showed that the correlation of plot volume with crown-cover percent was essentially the same regardless of the method used for measuring relative crown cover.

Correlation of Photo-volume with Various Photo-measurements

The various field data and photo-measurements which form the basis for this study are given in Table 1. The volumes in cubic feet for each plot are given separately for the trees 5 inches and larger (Y) and for the trees 7 inches and larger (Y′). The other symbols used are X_1 for stand height, X_2 for crown diameter, and X_3 for crown cover percent.

A preliminary test as to the relative importance of the various independent stand characteristics (X) can be made by computing the simple correlation coefficients between Y and X. These coefficients are shown in Table 2. It is at once evident that stand height is more closely related to plot volume than any of the other stand characteristics, and this is true for both Y and Y′. Next in importance is the correlation between plot volume and crown diameter. The lowest correlation exists between volume and crown-cover percent. Both stand height and crown diameter are, however, measures of the average size of the trees on a plot and their interrelation is indicated by the correlation coefficient of 0.519. A determination of the partial correlation coefficients between plot volume and crown diameter, which measures the closeness of the relationship between these two variables after the effect of stand height has been eliminated, indicates −0.032 for the volumes in trees 5 inches and larger and 0.060 for the volumes in trees 7 inches and larger. Neither of these coefficients is significant. The partial correlation coefficients between volume and crown diameter after eliminating the effect of both stand height and crown-cover percent are 0.079 and 0.119 respectively.

TABLE 2. Simple correlation coefficients between plot volume Y and stand characteristics X_1, X_2, X_3.

		Y	X_1	X_2	X_3
		For volume in trees 5 inches and larger			
Volume	= Y	1.0000			
Stand height	= X_1	.8412	1.0000		
Crown diameter	= X_2	.4218	.5190	1.0000	
Crown cover	= X_3	.2993	.1859	−.2239	1.0000
		For volume in trees 7 inches and larger			
Volume	= Y′	1.0000			
Stand height	= X_1	.8676	1.0000		
Crown diameter	= X_2	.4758	.5190	1.0000	
Crown cover	= X_3	.2240	.1859	−.2239	1.0000

These coefficients are likewise not significant. For these data, crown diameter as such has, therefore, no appreciable influence on stand volume, and stand volume may be estimated only from stand height and crown-cover percent.

The Aerial Stand Volume Equation

The above conclusion has been further substantiated by a multiple regression analysis in which plot volume was expressed as a linear function of 7 variables X_1 to X_7, where:

X_1 = Stand height
X_2 = Crown diameter
X_3 = Crown-cover percent
$X_4 = X_1X_3/100$
$X_5 = X_1X_2/100$
$X_6 = X_2X_3/100$
$X_7 = X_1X_2X_3/1000$

None of the regression coefficients of those variables which contain crown diameter as a component proved to be statistically significant. A simplified regression, containing the variables X_1, X_3, and X_4 only, yielded an error of estimate of practically the same magnitude as the 7-variable regression. Crown diameter could therefore be eliminated as a useful variable for the estimation of stand volume. The standard errors of the various regression coefficients b_0, b_1, b_2, b_3, and b_4 were still relatively large, particularly for the absolute term of the equation b_0, where the error actually exceeded the magnitude of the coefficient itself. Further tests of regression equations containing only two to four of the terms b_0, $b_1X_1 \ldots b_4X_4$ yielded highly significant regression coefficients for two equations only, namely

$$Y = b_1X_1 + b_3X_3 \qquad (1)$$

and

$$Y = b_3X_3 + b_4X_4\,, \qquad (2)$$

where X_4 is the combined variable $X_1X_3/100$. There was no appreciable difference between the standard errors of estimate of individual plot volumes for equations (1) and (2). It can easily be demonstrated, however, that equation (2) is a more adequate expression for stand volume in terms of stand height and crown-cover percent than equation (1). Figure 1 shows that stand volume increases linearly with stand height. Part of the variation in stand volume for a given stand height is due to the variation of crown density on the various plots. If the volumes of each plot are adjusted to a crown-cover percent of 100, the points cluster somewhat closer around a straight line. For stands of full crown closure, we may therefore write

$$Y = b_0 + b_1X_1 \qquad (3)$$

Notice that the fitted lines in Figure 1 indicate an average plot volume equal to

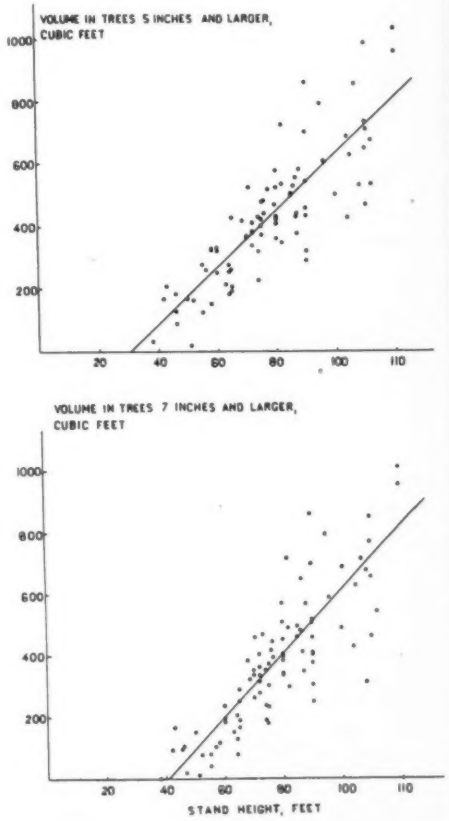

FIGURE 1. Individual plot volumes in terms of stand height.

zero for stand heights 29 and 41 feet for the trees 5 and 7 inches and larger respectively. If we multiply equation (3) by crown-cover percent X_3 and divide by 100 in order to obtain the adjusted stand volume corresponding to a given crown cover, the stand volume equation becomes

$$Y = (b_0 + b_1X_1)\frac{X_3}{100}$$

$$= \frac{b_0}{100}X_3 + b_1\frac{X_1X_3}{100}$$

$$= b_3X_3 + b_4X_4$$

which is identical with equation (2). Equation (2) which turned out to be the most suitable expression for stand volume in terms of stand height and relative crown cover has therefore a sound logical basis. Equation (2) implies that, for a given stand height, stand volume is proportional to relative crown cover. In contrast, equation (1) would imply that for a given increase in relative crown cover, the corresponding increase in stand volume would be the same regardless of the height of the stand. Such a contention is logically not sound; doubling the crown cover in a 100-foot tall stand would certainly mean a greater absolute increase in stand volume than that produced by doubling the crown cover in a 50-foot tall stand. Equation (2) may therefore be accepted as the best available expression of stand volume based on stand height and crown-cover percent.

The Aerial Stand Volume Tables for Upland Oak

The least squares determinations of the regression coefficients b_3 and b_4 of equation (2) are given in Table 3 together with their standard errors and other statistics relating to the stand volume equations. The stand volume tables themselves are given in Table 4. In Figure 2, the calculated volumes per 1/5 acre plot are plotted in terms of height for different crown-cover percentages. The various straight lines cross each other in a single point where volume per plot is equal to zero. This follows as a result of the mathematical form of the stand volume equation, since for

$$Y = 0 = b_3X_3 + b_4\frac{X_1X_3}{100}$$

$$= X_3(b_3 + b_4\frac{X_1}{100});$$

$$X_1 = -\frac{b_3}{b_4}\ 100;$$

which is equal to 29.7 feet for the volume in trees 5 inches and larger and 41.3 feet when 7 inches is taken as the lower diam-

TABLE 3. Numerical constants relating to the stand volume equation: $Y = b_3X_3 + b_4X_4$

Statistics relating to stand volume equation	For equation relating to cubic-foot volume in trees: 5 inches and larger	7 inches and larger
Regression coefficient (b_3)	-3.465 ± 0.649	-5.634 ± 0.679
Regression coefficient (b_4)	11.68 ± 0.80	13.64 ± 0.83
Standard error of estimate	108	113
Multiple correlation coefficient	0.85	0.87
c — multiplier (c_{33})	0.00003621	0.00003621
c — multiplier (c_{34})	−0.00004326	−0.00004326
c — multiplier (c_{43})	0.00005453	0.00005453

Y = Volume per 1/5 acre plot in cubic feet, including bark.
X_3 = Crown-cover percent.
X_4 = Combined variable crown-cover percent times stand height/100.

TABLE 4. Aerial stand volume tables for upland oak in central Pennsylvania.[1]

Stand height[2]	Crown-cover percent[3] 20	40	60	80	100
feet	*cubic-foot volume in trees 5 inches and larger per 1/5 acre plot*				
40	24	48	72	97	121
50	48	95	142	190	238
60	71	142	213	283	354
70	94	188	283	377	471
80	118	235	353	470	588
90	141	282	423	564	705
100	164	329	493	657	822
110	188	375	563	751	938
	cubic-foot volume in trees 7 inches and larger per 1/5 acre plot				
50	24	47	71	95	119
60	51	102	153	204	255
70	78	156	235	313	391
80	106	211	317	422	528
90	133	266	399	531	664
100	160	320	480	640	801
110	187	375	562	750	937

[1]The basic data were collected in stands of average to good site quality. The unified local volume table used in computing the individual plot volumes is as follows:

D.b.h., inches	6	8	10	12	14	16	18	20
Vol., cu. ft.	4.16	8.06	13.47	20.48	29.20	39.70	52.05	66.33
D.b.h., inches	22	24	26	28	30	32	34	
Vol., cu. ft.	82.57	100.85	121.25	143.80	168.55	195.50	224.75	

[2]The average height of the three tallest trees on a 1/5 acre plot.

[3]Determined by crown density scale.

eter limit of measurement. It is to be expected that stand volume approaches zero at a greater stand height X_1 if only the trees 7 inches and larger are considered than when the volume refers to the trees 5 inches and larger. In comparing the two volume tables, notice that within the entire range of actual observations, that is, up to a stand height of 110 feet, the volume in trees 7 inches and larger remains lower than the volume in trees 5 inches and larger.

The standard error of estimate of the individual plot volume as compared with the tabulated volumes is equal to 108 and 113 cubic feet respectively (Table 3). This amounts to 25 and 29 percent of average plot volume. The error is of about the same magnitude as the corresponding standard error of estimate of yield table volumes (15 to 20 percent for yields in cubic feet, 25 to 40 percent for yields in

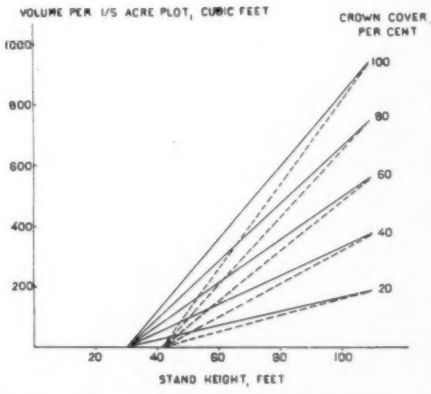

FIGURE 2. Graphical representation of aerial stand volume tables for upland oak.

Volume in trees 5 inches and larger ———
Volume in trees 7 inches and larger – – – –

board feet). The standard error of the tabulated volumes themselves varies between ± 5 and ± 15 cubic feet for small and average volumes, and between ± 15 and ± 25 cubic feet for large volumes. The c-factors used in the calculation of these standard errors are listed in Table 3. They are independent of Y and are therefore the same for the two volume equations.

A few precautionary remarks are in order to prevent any possible misinterpretation of the data given with regard to the accuracy of the tables presented. The standard error of estimate of individual plot volumes is due mainly to random variation in plot volume for given heights of the three tallest trees and given crown closures. In actual application, the additional error of the photogrammetric measurements of tree height and crown closure will further reduce the accuracy of an estimate of volume per plot. Furthermore, the errors of height and crown cover measurement are partly accidental errors of measurement and partly systematic errors, and they differ from one photo-interpreter to the next. Finally, it must be remembered that Table 4 is based on the determination of volume from a composite average local-volume table and any differences in the degree of utilization or extremes of site quality might greatly affect the determination of actual plot volume. The use of an average unified local volume table for the original determination of plot volume was, of course, not necessary. Even with more accurate determination of plot volume, however, systematic errors in the application of aerial stand volume tables occur due to a number of other factors, such as deviations from the anticipated degree of utilization. In order to avoid systematic errors of a serious nature in a timber cruise based on aerial stand volume tables, whether they be due to systematic errors of measurement or inaccuracies of the basic volume table, it is important to provide the necessary ground control for the elimination of such errors. This is done by measuring on the ground the volume of a selected number of stands 5 to 10 acres in size and comparing the actual volume of these stands with the calculated photo-volume based on the measurement of 10 to 20 one-fifth acre plots within each stand. The ratio of the actual volume to the calculated photo-volume will provide correction factors for the photo-volumes of the plots of the entire cruise. If these correction factors are plotted as a function of photo-volume, they may be found to change considerably in terms of average volume per plot. In a specific test of this type the adjustment factors actually increased from 0.9 to 1.2 for plot volumes between 180 and 300 cubic feet. For higher volumes up to about 400 cubic feet, the adjustment factor again decreased to a value of 1.1 and less.

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Chlorosis, Mycorrhizae and the Growth of Pines on a High-Lime Soil

BY

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CERTAIN SPECIES of coniferous trees are well adapted to planting in sub-humid and semi-arid regions for wood production, as wind breaks, or for watershed protection on steep lands. Soils of these regions tend to be calcareous, however, and many drought-enduring species become chlorotic and make poor growth on them.

The cause or causes of lime-induced chlorosis have been variously explained by different workers. Whatever its causes, this physiological disease is seldom encountered in natural plant communities. Lindner and Harley (1944) pointed out four types of chlorosis which presumably are due to nutrient interrelations: True iron deficiency can be produced in nutrient cultures by omitting iron or supplying the element in low quantities. Heavy applications of phosphorus fertilizer in nutrient culture, or in the field, can cause chlorosis by forming complex insoluble precipitates with calcium and iron. Chlorosis of pineapple on certain soils has been attributed to an upset manganese-iron ratio. Lime-induced chlorosis is encountered widely on calcareous soils and has been reported to affect many chlorophyll-bearing plants. Most research indicates that lime-induced chlorosis is in some way associated with, or due to, improper utilization of iron within the plant.

Thorne, Wann and Robinson (1951), summarizing literature concerning lime-induced chlorosis, state that the disorder occurs on soils having basic reactions and high lime contents, but that sometimes no distinct difference in soil pH or percentage of lime have been found between soil areas where plants were green and adjacent areas where they were chlorotic. Chlorosis develops most severely on soils with fine texture, high moisture content, poor aeration and low temperatures. These conditions do not prevent iron uptake but apparently aid in inactivating iron within the plant. High potassium in chlorotic leaves and disturbed potassium-calcium ratios seem to be a result of chlorosis rather than a cause. There is no evidence that high phosphate, causing precipitation of iron in soils or plants, is a general cause of lime-induced chlorosis, nor are large amounts of available manganese an important factor. Chlorotic leaves generally are higher in total and soluble nitrogen and organic acids than normal leaves. Chlorotic plants often respond to iron salts even though there is no consistent difference in total iron content be-

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tween chlorotic and normal leaves. These authors suggest that the oxidation of iron to the ferric state and its possible inactivation in protein combinations, followed by a disturbance in the protective protein-chlorophyll combination, appears to partly explain relationships involved in chlorosis.

The relations of mycorrhizae to chlorosis on high-lime soils are not clear. McComb (1943) has noted that certain non-mycorrhizal conifers failed to grow on both highly calcareous Webster prairie soil and on acid, O'Neill prairie soil. In Iowa, when nursery stock with mycorrhizal roots is planted on high-lime soils, the seedlings may become chlorotic the first year and die within a period of 3 to 5 years, or the chlorosis may develop more slowly and the trees persist for 10 to 15 years or more. Chlorotic conifers have fewer and smaller needles than normal plants. In time, individual branches die back and the whole tree eventually dies. (Fig. 1). Some species such as *Pinus nigra austriaca* and *Larix decidua*, may remain healthy and continue to make satisfactory growth on these soils.

Little is known about the ecology of mycorrhizal fungi in high-lime soils. Waksman and Starkey (1931) state that fungi are comparatively more numerous than bacteria in acid as contrasted to neutral and alkaline soils. Clark (1954) states that dominance of a single species or group of soil organism cannot be ascribed to a single factor under a variety of accompanying conditions. He suggests that, with an alkaline substrate, fungi may be repressed not simply by alkalinity, but largely by a vigorous bacterial growth.

Field observations of conifers planted on calcareous soils suggest that chlorosis may be less severe on uneroded soils well supplied with organic matter. The importance of quantity and kind of organic matter in relation to mycorrhizae is suggested, but not proven, and the relationship is undoubtedly complex. Clark (1954), discussing antibiosis in relation to microbial growth and dominance states "apparently there exists in the soil a fungi-static factor whose profile distribution coincides with that of the organic matter content of the soil. The inhibiting factor is masked by the presence of added nutrients or by the presence of nutrients released from microbial bodies killed by heat." Gottlieb (1954) states that antibiotics are formed in soil when such soils are altered by heat sterilization or by amendments with plant products or other nutrients. Antibiotics added to normal soils may be inactivated by the surface-active components, by chemical combination with other constituents, or by the hydrogen-ion concentration. Brian *et al.* 1945 report that antibiotics of the gliotoxin or viridin group are toxic to mycorrhizal fungi and are believed at least partially responsible for the infertility of the Wareham Heath in England and the difficulties encountered in reforesting it.

The Iowa Agricultural Experiment Station, in cooperation with the Ames Branch, Central States Forest Experiment Station, is currently studying the growth of some 20 species of conifers on highly calcareous soils in western Iowa. The purpose of the exploratory pot-culture experiment described here was to determine if pine suffers from a correctable chlorosis-causing nutrient deficiency on the calcareous phase of the Ida soil. *Pinus banksiana* Lamb. was used as a test plant.

Experimental

The soil used in this experiment was the C_1 horizon of Ida silt loam taken from a depth of 2 to 3 feet about three miles west of Mapleton, Iowa. This soil material is a loess of late Pleistocene origin and is a grayish brown to light gray, coarse silt loam which crumbles into a powder when dry. It is very calcareous, lime concretions are present, and the pH of the lot used was 8.2. "Available" phosphorus by acid extraction amounted to 4 pounds per acre and "available" potassium 196 pounds. The calcium carbonbate equivalent was about 5 percent, and total soluble salts amounted to 120 p.p.m.

Soil of known moisture content was weighed into one-gallon stone crocks equipped with drains. The crocks were weighed weekly during the experiment, and moisture losses were replaced with distilled water to maintain the pots at or near field capacity.

Treatments were selected to cover the range of nutritional factors possibly associated with chlorosis. The general consensus of opinion from the literature is that chlorosis on high-lime soils can be corrected by treatment with iron. Accordingly, iron treatments were given a maximum number of degrees of freedom in the experiment. In view of the exploratory nature of the experiment and the large number of factors involved, a split-plot design was used with iron treatments assigned to the whole plots. The source of each nutrient and the quantities applied are shown more fully in Table 1. Nitrogen, phosphorus, and potassium were applied at rates of 200 pounds per acre[1] respectively. The micronutrients, which consisted of zinc, copper, molybdenum, boron, and manganese, were applied together, each at the rate of 20 pounds per acre.

Part of the original soil (pH 8.2) was treated with concentrated sulfuric acid to

[1]An acre of soil expressed as the acre-furrow-slice is considered to weigh 2,000,000 pounds.

FIGURE 1. Planted 28-year-old red pine on calcareous Storden soil, Ames, Iowa. Chlorotic and dying trees in foreground are on soil which has a surface pH of 7.1. Normal trees in right background are on slightly acid soil.

TABLE 1. Source of nutrients and rate of application.

Nutrient	Source	Wt. per liter stock solution, gm.	Ml/ stock sol. per kg. soil	Pounds per acre
N	$NaNO_3$	24.274	25	200
K	KCl	7.563	25	200
P	$NaH_2PO_4 \cdot H_2O$	17.820	25	200
NP	$NaNO_3$	24.274	25	200
	$NaH_2PO_4 \cdot H_2O$	17.820		
PK	KH_2PO_4	13.922	25	200
	$NaH_2PO_4 \cdot H_2O$	3.700		
NK	KNO_3	10.344	25	200
	$NaNO_3$	15.576		
NKP	KNO_3	10.344	25	200
	$NaNO_3$	15.576		
	$NaH_2PO_4 \cdot H_2O$	17.820		
Micro-nutrients	$ZnSO_4 \cdot 7\ H_2O$	1.759	25	20
	$CuSO_4 \cdot 5\ H_2O$	1.571		
	MoO_2Cl_2	.675		
	H_3BO_3	2.286		
	$MnSO_4 \cdot 4\ H_2O$	3.669		
Fe	Sequestrene[1]	6.997	25	20
	Sequestrene[1]	69.970	25	200
	$Fe_2(SO_4)_3 \cdot 9H_2O$	24.151	25	200

[1]Na-Fe-Ethylenediamine tetra-acetate.

establish two new pH levels. All other treatments were at the check level of pH 8.2. The soil listed as pH 6.1 changed gradually during the experiment to a final pH of 6.9, while the soil listed as pH 7.2 changed to pH 7.3.

Iron was applied to the soil at the rate of 20 pounds per acre as Na-Fe Sesquestrene, or at the rate of 200 pounds per acre as either $Fe_2(SO_4)_3 \cdot 9H_2O$ or Sequestrene. Sequestrene is the trade-name for ethylenediamine tetra-acetate. The compound belongs to a class of organic substances which are known as chelating agents and are capable of reacting with the heavy metals to form compounds which remain soluble over a wide pH range. Recent workers (Jacobsen 1951, Stewart and Leonard 1952) have shown that iron chelated with Sequestrene remained available to plants in alkaline media.

The humus applied to one series of the split plots was obtained from an established healthy pine plantation near Ames, Iowa. The loose, undecomposed litter was raked away to obtain decomposing organic matter at the junction of the A_0 and A_1 horizons. The unsterilized humus (pH 4.4) was steeped in a solution of $Fe_2(SO_4)_3 \cdot 9H_2O$ equivalent to the 200 pound per acre stock solution, drained off, and the humus applied directly to the soil. Applications of 40 gm. of humus were made by stirring the humus into the upper 2 inches of soil before the seeds were planted. The humus applications amounted to aproximately 1.5 percent of the oven-dry weight of the soil.

Jack pine was chosen as an indicator species because of its rapid juvenile growth and small seed size. The seeds were soaked in distilled water for six hours, surface sterilized with Arasan, and planted immediately. No signs of damping-off were detected. After about two weeks the seedlings were thinned to twelve per crock.

The nutrients were added in four appli-

cations over a period of four weeks, rather than in one application, in order to avoid injury to the plants.

The experiment was started in a greenhouse so that the growing season could be lengthened. As soon as the danger of frost was past, the experiment was moved outdoors to avoid the high temperatures of the greenhouse in summer.

The crocks were sunk into the soil to keep them within the soil temperature ranges normally encountered by growing palnts. A cover was constructed of flexiglass to keep precipitation from reaching the crocks. Whenever possible the covering was removed to expose the seedlings to full sunlight. Generally, the seedlings were exposed to about 6,000 foot-candles at noon.

TABLE 2. Average height growth in inches above cotyledons of jack pine seedlings on calcareous Ida soil in response to macro- and micro-nutrients, soil acidification, and treatment with unsterilized humus.

			Split plots		
Whole plots	Humus	Check	Seq. 20	Seq. 200	$Fe_2(SO_4)_3$
Check (pH 8.2)	1.28	0.71	0.75	0.64	0.69
N	1.23	0.76	0.71	0.69	0.80
P	1.74	0.70	0.77	0.69	0.69
K	1.24	0.70	0.65	0.65	0.69
NP	1.82	0.82	0.87	0.76	0.76
PK	1.48	0.81	0.75	0.70	0.71
NK	1.43	0.74	0.68	0.72	0.71
NKP	1.18	0.78	0.91	0.67	0.71
Micronutrients	1.51	0.67	0.71	0.66	0.68
NKP + micros	1.04	0.89	1.02	0.81	0.79
pH 6.1	1.94	1.26	1.27	0.91	1.22
pH 7.2	2.06	1.13	0.95	0.83	0.95
Ave. split plots	1.50	0.83	0.84	0.73	0.79

TABLE 3. Average fresh weight of jack pine seedlings grown on calcareous Ida soil in response to macro- and micro-nutrients, soil acidification, and treatment with unsterilized humus, grams.

			Split plots		
Whole plots	Humus	Check	Seq. 20	Seq. 200	$Fe_2(SO_4)_3$
Check (pH 8.2)	1.180	0.357	0.349	0.283	0.373
N	1.318	0.614	0.370	0.363	0.321
P	1.599	0.475	0.521	0.367	0.333
K	1.025	0.475	0.295	0.303	0.336
NP	2.024	0.572	0.640	0.352	0.393
PK	1.208	0.434	0.455	0.303	0.313
NK	1.314	0.396	0.329	0.402	0.295
NKP	0.954	0.418	0.617	0.405	0.404
Micronutrients	1.341	0.301	0.364	0.334	0.268
NKP + micros	0.657	0.498	0.586	0.400	0.385
pH 6.1	1.663	0.669	0.696	0.353	0.588
pH 7.2	2.179	0.589	0.741	0.323	0.383
Ave. split plots	1.372	0.483	0.497	0.349	0.366

At the end of the growing season total height and height growth above the cotyledons were measured to the nearest 0.1 inch. The roots were washed out and examined for mycorrhizae with a binocular microscope. Total fresh and dry weights of the living plants from each crock were measured to the nearest 0.05 gm. Dry weight determinations were on plants dried to constant weight in an oven at 105° Centrigrade.

Results

Results of the pot culture experiment presented in Tables 2 and 3 show the response of jack pine seedlings to macro- and micronutrients, soil acidification, and unsterilized humus. The data are height growth above cotyledons and fresh weight, respectively. Total height and dry weight data are not included, since they show the same relationships as the data presented. Figure 2 shows the whole plot which received nitrogen and potassium at 200 pounds per acre.

FIGURE 2. Growth of jack pine seedlings on calcareous Ida soil in response to 200 pounds per acre of nitrogen and potassium. Additional treatments: Humus, 1.5 percent by weight; None, no additional treatment; Fe 200 pounds per acre as Fe $(SO)_3 \cdot xH\ O$; Fe—20 pounds per acre as ferric sequestrene; and Fe—200 pounds per acre as ferric sequestrene.

Seed germination and early growth were aparently normal in all treatments. At five weeks after germination it was observed that seedlings in pots receiving humus were beginning to make new growth. The plants in all crocks were green and normal in appearance at that time.

By mid-July, or ten weeks after germination, all seedlings in pots receiving humus were growing well. All seedlings on acidified soil were normal in color, but only those with humus in addition to acidification were making new growth. The other seedlings were pale green and needle tips were becoming purple.

At the end of the growing season marked differences in color were evident. Seedlings in pots not receiving humus were apparently on the verge of death. No new growth had been made beyond the few whorls of primary needles put on early in the season before discolorations began to appear. During the summer the zone of purple moved down toward the base of the needles, followed by a broad zone of yellow, and finally a dying-back of the needle tips. The symptoms appeared on trees in all crocks not receiving humus. Seedlings in pots receiving humus were normal in color and general appearance except for those receiving NPK + micronutrients and humus. These trees made new growth but developed discoloration symptoms similar to the seedlings grown without humus. Necrosis of the needle tips did not, however, occur. The few secondary needles which developed were a much brighter green than normal. In some crocks receiving phosphorus and humus but no nitrogen, the foliage was light green and the lower needles died.

The short roots of trees grown on humus-treated soil were found to be mycorrhizal when examined under a binocular microscope. Since the roots were not sectioned the structures of the mycorrhizae are unknown. From previous work (McComb and Griffith, 1946) it is assumed that those with visible external mantels were ectotrophic or ectendotrophic and that those hypertrophied short roots without a

visible mantel were ectotrophic but with a mantel so smooth and compact as to be invisible under the binocular. In uninoculated soil, the short roots were not hypertrophied and were assumed non-mycorrhizal. Large segments of the root system of non-mycorrhizal plants sloughed off easily and extreme care was required when the roots were washed out.

The roots were distributed fairly uniformly through the soil. Figure 3 illustrates the root systems of trees in the check treatment with no fertilizer, with iron at 20 pounds per acre, and with humus.

Tables 4 and 5 contain statistical analyses of the growth data summarized in Tables 2 and 3. While both criteria furnish essentially the same information, height growth above the cotyledons was a more sensitive measure of vigor than fresh weight. The seedlings apparently made normal growth up until new shoot growth began. The use of height growth above the cotyledons as the criterion of vigor eliminates growth attributed to reserve materials present in the seed.

The mean square of the height growth data for the treatments to whole plots was found to be highly significant, whereas the mean square of the fresh weight data was not significant. When the sums of squares for whole plot treatments were segregated, it was found with height growth data that both soil acidification treatments were significant at the one-percent level. Segregation of the sums of squares for fresh weight data showed only significance at the 5-percent level. Neither height growth data nor fresh weight data showed a significant difference between the two pH levels of acidified soil.

Highly significant differences for split-plot treatments were found in the data for both criteria. Segregation of the sum of squares for these treatments showed that the humus treatment produced highly significant differences. In fact over half the total sum of squares is attributed to the humus treatment. A significant difference between the two levels of Sequestrene was found in the height growth data. Examination of the data in Tables 2 and 3 shows that growth was inhibited when iron was supplied either as Sequestrene or as ferric sulphate at the rate of 200 pounds per acre. There was no significant difference between plants grown with and without iron fertilization.

Discussion

The pot-culture study has yielded information on the importance of mycorrhizae in nutrition on high-lime soils. When normal mycorrhizae were present, Jack pine did not suffer chlorosis. The iron fertilizers in the absence of mycorrhizae did not prevent a disorder of pine which was thought to be lime-induced chlorosis. Iron at the higher rates of Sequestrene and ferric sulphate may actually have been toxic, for yields were lowest at the high iron level.

Examination of the fresh weight data in Table 3 shows the effect of fertilizers when applied to the inoculated crocks. Comparison of the yields from crocks with potassium with those receiving similar treatment but no potassium suggests ion antagonism, with higher concentrations of potassium possibly affecting availability of other ions. Nitrogen and phosphorus increased growth

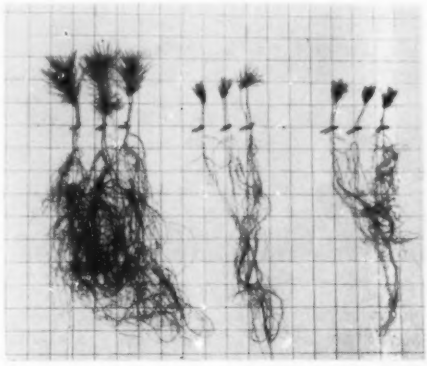

FIGURE 3. Root systems of one-year-old jack pine grown on calcareous Ida soil in the check plot. Additional treatments: (L to R) Humus, 1.5 percent by weight; None, and Fe —20 pounds per acre as ferric sequestrene.

TABLE 4. Statistical analysis of height growth data summarized in Table 2.

Source	Degrees of freedom	Sum squares	Mean square	F
Reps	1	0.0422		
Whole plots	11	2.8402	0.2582	5.216**
N	1		0.0505	1.020
P	1		0.1117	2.257
K	1		0.0419	0.846
NP	1		0.0032	0.065
PK	1		0.0738	1.491
NK	1		0.0010	0.020
NPK	1		0.0409	0.826
pH 6.1 vs pH 7.2	1		0.0911	1.840
pH 6.1 vs check	1		1.2802	25.836**
pH 7.2 vs check	1		0.6882	13.903**
micros vs check	1		0.0216	0.436
Error (a)	11	0.5451	0.0495	
Split plots	4	9.5964	2.3991	78.402**
Humus vs others	1		9.4080	307.451**
Check vs irons	1		0.0430	1.405
Seq 20 vs seq 200	1		0.1452	4.745
Seq vs ferric sulfate	1		0.0002	0.006
Split plots × whole plots	44	1.6370	0.0372	1.216
Error (b)	48	1.4701	0.0306	
Total	119	16.1310		

**Significant at the 1 percent level. *Significant at the 5 percent level.

TABLE 5. Statistical analysis of fresh weight data summarized in Table 3.

Source	Degrees of freedom	Sum squares	Mean square	F
Reps	1	0.2775		
Whole plots	11	1.9087	0.1735	2.736
N	1		0.1381	2.178
P	1		0.2501	3.945
K	1		0.2587	4.080
NP	1		0.0008	0.013
PK	1		0.0788	1.243
NK	1		0.0177	0.279
NPK	1		0.0186	0.293
pH 6.1 vs pH 7.2	1		0.0091	0.143
pH 6.1 vs check	1		0.4243	6.692*
pH 7.2 vs check	1		0.5574	8.792*
micros vs check	1		0.0008	0.013
Error (a)	11	0.6980	0.0634	
Split plots	4	17.7500	4.4375	51.600**
Humus vs others	1		17.3481	201.722**
Check vs irons	1		0.0870	1.012
Seq 20 vs seq 200	1		0.2625	3.052
Seq vs ferric sulfate	1		0.0523	0.608
Split plots × whole plots	44	3.3334	0.0758	0.881
Error (b)	48	4.1280	0.0860	
Total	119	28.0956		

**Significant at the 1 percent level. *Significant at the 5 percent level.

of seedlings in inoculated crocks when potassium was not present. Seedlings grown on inoculated soil developed toxicity symptoms if both NPK and micronutrients were added. The symptoms were similar to those found on all uninoculated seedlings, although new growth was not completely arrested and needle tips did not become necrotic.

Soil acidification treatments produced a significant increase in average growth. The plants grown on the acidified, uninoculated soil remained green longer than plants on unacidified, uninoculated soil, but the same symptoms eventually developed on both. Obviously growth conditions were more favorable on the acidified soil, but acidification alone did not permit normal growth, while inoculation with mycorrhizal fungi on otherwise untreated soil permitted normal, although not maximum, growth.

It is a common belief based on a mass of observational evidence that many pines canont be grown on soils with reactions in the alkaline range. Slow growth, gradual yellowing and eventual death is the common fate on such soils. Yet there are many examples of pines and other temperate zone conifers surviving and growing satisfactorily on high-lime soils. In Iowa *Pinus strobus*, *P. nigra austriaca*, and *Larix decidua* have been found thriving in soils with pH values of 7.8 or above throughout the entire profile. One author has studied healthy stands of *Pinus sylvestris*, *P. nigra austriaca*, *Picea excelsa*, and *Larix decidua* in central Europe on soils with pH values of 7.8 or above at the surface and in all horizons. The results of the experiment reported here suggest that nutrition and growth will be normal if healthy mycorrhizae form. There is a question, however, as to whether a satisfactory mycorrhizal relationship can be maintained from year to year over the life span of the tree, in such soils.

The results of this experiment, in relation to existing studies on tree mycorrhizae, emphasize the need for a comprehensive study of the ecology of the mycorrhizal fungi, especially in relation to the amount and character of soil organic matter, antibiosis and microbial competition, and to the basic factors of soil reaction, nutrient levels, moisture supply, aeration, and temperature.

Summary

Jack pine was grown from seed on calcareous Ida silt loam of pH 8.2 to determine if a chlorotic condition frequently observed on pines in field plantations could be corrected by treatment with NPK fertilizers alone, in combination with each other and with certain micro-nutrients; by acidification of the soil; by soil inoculation with unsterilized humus from a healthy pine plantation; and by treatment with different sources and levels of iron.

Normal growth was obtained only in soil treated with unsterilized humus. All the seedlings in humus-treated soil possessed mycorrhizae while seedlings in the other treatments were not mycorrhizal. Soil acidification produced a significant increase in growth as compared to the controls, but the seedlings were not normal and probably would not have survived the second growing season. None of the iron treatments, alone or in combination with NPK in the absence of the mycorrhizae, prevented chlorosis.

The results are briefly discussed in relation to the possibility of obtaining normal pine growth on high-lime soils. A need exists for a comprehensive study of the ecology of the soil fungi which form mycorrhizae.

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Restauration des terrains au-dessus de la limite supérieure de la vegetation forestière. By Dr. L. Liakos.

(Restoration of soils above the upper limit of forest vegetation. Pastoral ameliorations on the southern Alps.)1954. Published by the author, 82b Apostle Paul Str., Thessaloniki, Greece. 139 pp. $3.00.

REVIEW by George T. Tsoumis
University of Thessaloniki

THE BOOK is Dr. Liakos' doctorate dissertation, which was submitted to the University of Nancy (École National des Eaux et Forêts), France, in June 1953. The author presents a thorough study of the alpine zone (i.e. the zone above the upper limit of forest vegetation) from the point of soil, climate and vegetation, as well as of the means and methods of restoration of degraded alpine areas. In contrast to lower elevations, the protective role in the alpine zone is exercised by the herbaceous vegetation, since forest trees cannot live there. Taking into consideration that the instability of the soils of the alpine zone contributes greatly to the creation of floods, the practice of soil erosion control is of great importance there, because it can lead to the reestablishment of equilibrium in the watershed relations of degraded mountainous areas.

The first part of the book is general. It contains a chapter on the efficacy of the vegetation on the restoration of mountainous areas, a chapter on the soil and climatic conditions of the high mountains, and another on the problem of restoration of degraded alpine areas in hot countries. In the second part the author presents his observations made on the Southern Alps, and more specifically in the valley of Tinée, of the Maritime Alps. This part contains observations regarding the instability of alpine areas in this valley, and a description of the work which is being done there. A chapter containing a detailed and systematic study of the vegetation of the alpine zone, especially the area suited for grazing, closes the second part. In the third part the methods and means of restoration are discussed. A chapter is devoted to the techniques of stabilization of the areas under consideration, another to the fixation of the soil of these areas by planting valuable grazing plants, and a third one to the measures to be taken, after the stabilization and fixation works are finished, for the conservation of the established grazing areas.

Height Growth of Loblolly Pine Seedlings in Relation to Seedling Characteristics

BY

KARL F. WENGER

THE CONNECTION between the appearance and the vigor of tree seedlings has been universally recognized in a general way for a long time. With the intensification of forestry practices, however, more definite criteria of seedling vigor are needed. The need is especially strong in even-aged management when natural reproduction is relied upon to establish the next stand. In even-aged management of loblolly pine (*Pinus taeda* L.) the success or failure in attaining a specified stocking of reproduction must be determined to decide what additional silvicultural measures may be needed. We need to find out how to tell which seedlings may survive to become part of the future stand. Reasonably reliable criteria of future seedling growth are essential to distinguish between seedlings of good and poor prospects.

Little work has been done on the relation of seedling growth to seedling characteristics. Wahlenberg,[1] studying the behavior of loblolly pine reproduction in selection stands, found that lower overstory densities were associated with greater height, ground-line diameter, foliated portion of the stem, branch-bearing portion of the stem, number of branches, branch length, needle length, needle weight, bud length, and bud weight of 3-year-old seedlings. However, quantitative relations between growth and easily measured characteristics of loblolly pine seedlings have not been determined. A study therefore was made to find which characteristic of loblolly pine seedlings is the best indicator of height growth, and how the relation is affected by gross soil differences, previous burning, age, and attack by the Nantucket pine tipmoth (*Rhyacionia frustrana* Comst.).

Procedure

In the fall of 1951, 700 seedlings were selected in clearcut areas of the Bigwoods Experimental Forest. They were distributed among soil groups, surface conditions, and ages as shown in Table 1.

The following characteristics were recorded for each seedling not infested by the tipmoth:

1. Total height.
2. Proportion of the stem bearing needles.
3. Proportion of the stem bearing branches.
4. Number of branches.
5. Needle length (of fully developed needles along the main stem).

[1]Wahlenberg, W. G. 1946. Effect of overwood on survival and development of loblolly pine seedlings in southern Arkansas. U. S. For. Serv. Sth. For. Exp. Sta. Typewritten office report.

The author is stationed at Franklin, Va., and is a member of the Southeastern Forest Experiment Station, Forest Service, U. S. Dept. of Agriculture.

TABLE 1. Distribution of sample seedlings among soils, surface conditions, age, and insect attack.

Soil groups and surface condition[1]	2-year-old seedlings		4-year-old seedlings	
	Not infested	Infested[2]	Not infested	Infested[2]
	Number	*Number*	*Number*	*Number*
Well-drained, friable subsoil, not burned	100	----	100	----
Well-drained, friable subsoil, burned	100	----	----	----
Well-drained, plastic subsoil, not burned	100	100	100	100

[1]Grouping of soils is based on surface drainage and consistency of the subsoil. In this case the well-drained, friable group (WF) was represented by loamy fine sands and fine sandy loams with somewhat heavier material appearing below 20 inches. The well-drained, plastic group (WP) was represented by relatively shallow, very fine sandy loams or silt loams grading into very fine sandy clay or silty clay at 5 to 8 inches. Well-drained soils include those with good and imperfect surface drainage.

[2]The Nantucket pine tipmoth.

6. Terminal bud length.
7. Stem form quotient (ratio of mid-height diameter to ground-line diameter).
8. Height-diameter ratio (ratio of total height to midheight diameter).

The seedlings were located within strips 20 links wide. Those chosen for the infested group were located within the same strips as the undamaged seedlings, so that the two kinds were intermingled and subject to identical environmental conditions. Seedlings showing evidence of tipmoth attack before the last growing season were excluded from the infested group. Thus, the results would not be affected by varying numbers of earlier attacks. Since damage to the terminal buds of infested seedlings prevented satisfactory measurement of length of terminal bud and height of main stem, only total height (to the highest extremity of the crown excluding needles), number of branches, and needle length were recorded. Initially uninfested seedlings that were attacked while the study was in progress were excluded from the data, whereas infested seedlings were not. Many of the 2-year-old but few of the 4-year-old infested seedlings were attacked again during the year of observation. Thus, seedlings that had been attacked in both years or in the preceding year only were compared with seedlings that had never been attacked.

The study was carried through the second growing season so that the relation of current growth to previous growth could be compared with the relations derived from the first year's data. The previous year's growth of the very slow-growing seedlings could not be distinguished with confidence at the time the study was installed.

Results

The significant relations derived from the first year's data are shown in Figure 1. This initial analysis did not include the seedlings infested by the tipmoth.

Multiple and simple correlation coefficients were computed to find how closely height growth could be predicted. The coefficients for the specified independent variables with height growth are as follows:

Height-diameter ratio and height	0.96
Main stem foliation and height	.94
Terminal bud length and height	.91
Needle length and height	.90
Stem form quotient and height	.89
Number of branches	.85

These coefficients are all very high, indicating that all the derived curves fitted the data closely.

Since any one of these characteristics would predict seedling growth with satisfactory precision, the one that was most promising for field use could be chosen on the basis of ease of application. The number of branches was most satisfactory in

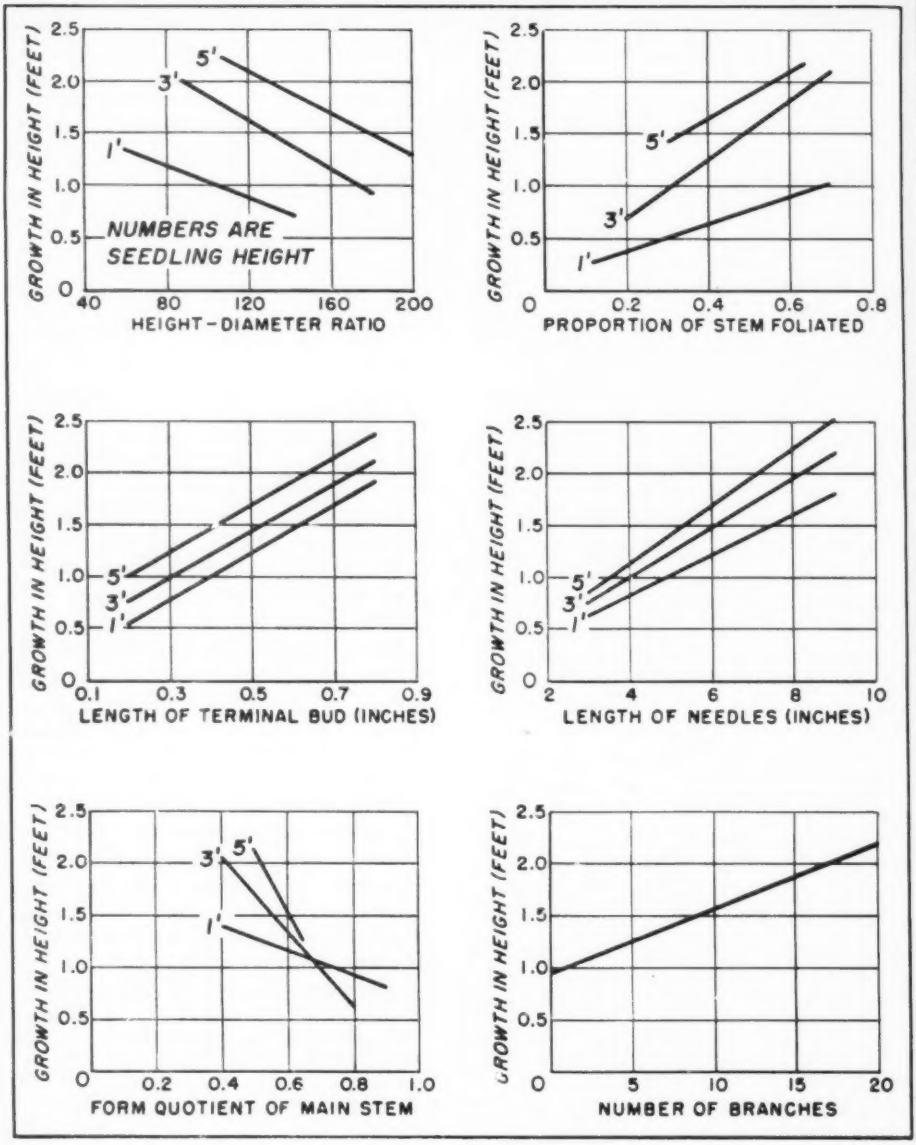

FIGURE 1. Relationship of one year's height growth to indicated seedling characteristics.

that respect because its relation to seedling growth was linear and independent of seedling height, and it could be determined without a measuring instrument. Therefore, the relation of seedling growth to number of branches was examined further to determine how it was affected by environmental conditions, age, and tipmoth attack. With age taken into account, height should also be closely related to growth. A similar analysis, therefore, was made of the relation of growth to height. The second year's data were analyzed in the same way. In addition, the relation of current to previous year's growth was determined. Tipmoth-infested seedlings were excluded in the second year because the initial classification of tipmoth infestation was no longer applicable.

The effects of soil and seedling age on the relations of current growth to branching, height, and previous growth in the second year are shown in Figure 2. These effects were not significantly different from those in the first year in the case of the branch and height relations. In the first year, however, the relation of growth to height was curvilinear.

The effect of the soil difference on the growth of the older seedlings is significant when growth is related to height but not when growth is related to number of branches. Thus, 5-year-old seedlings of a given height had larger crowns and grew faster on the lighter than on the heavier soil. However, on both soils their current growth bore the same relation to their previous growth.

In contrast to the older seedlings, the younger seedlings of a given height and number of branches grew faster on the heavier soil. In the relation of current to previous growth, the only significant difference was caused by the greater current growth of the 3-year-old seedlings on the heavier soil (Fig. 2, c). The area in which these seedlings were located had been disked before the harvest cut, which could conceivably have improved the soil characteristics enough so that the seedlings grew faster than on the lighter, normally better soil.

The effect of burning is not shown in the graphs. Seedlings of the same initial height grew 0.43 foot more in the first year and 0.48 foot more in the second year

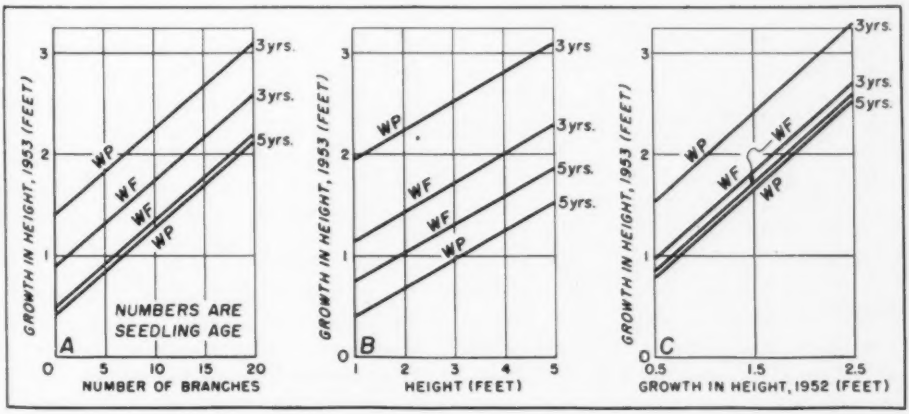

FIGURE 2. The effect of soil and age on the relations of current seedling height growth to number of branches, initial height, and previous height growth. WP *means* well-drained plastic soil, *and* WF *means* well-drained friable soil.

on the burned than on the unburned area. Seedlings with the same number of branches grew 0.37 foot more in the first year and 0.56 foot more in the second year in the burned than in the unburned area. That comparison involved only the younger seedlings on well-drained, friable soil (Table 1). This result agrees with earlier findings that loblolly pine seedlings in a burned area grow faster than those in an unburned area.[2]

The differences in height growth associated with initial tipmoth attack were quite unexpected. Infested 2-year-old seedlings grew 0.32 foot, a significant amount, more in height than uninfested seedlings of the same height and branching, and infested 4-year-old seedlings grew 0.45 foot more than uninfested seedlings of the same height and branching. The conduct and observations of this study suggest no rational explanation for that behavior.

The variation in height growth of similar seedlings attributable to soils, surface conditions, age, and tipmoth attack was accounted for by covariance analyses. The following multiple correlation coefficients show how closely the indicated seedling characteristics were associated with subsequent height growth when the above factors were taken into account:

First year	
Number of branches	0.90
Initial height	0.92
Second year	
Number of branches	0.87
Initial height	0.89
Previous season's growth	0.93

The correlation of current with previous growth is significantly higher than the correlations of growth with number of branches or initial height.

Discussion

The use of branching and seedling height as indicators of future growth is complicated by the influence of environmental factors. Different parts of seedlings do not remain in the same relation to each other with changes in soil conditions. Thus, seedlings of the same age and height had developed more branches on the lighter than on the heavier soil, and seedlings with the same number of branches or of the same height grew faster in one place than in another.

Growth, however, reflects environmental differences in about the same way in one year as in the next. Consequently, the relation of current height growth to previous height growth should be largely independent of these differences as long as the environmental conditions do not change appreciably from year to year.

Such a change might have caused the significantly faster growth for a given amount of previous growth of the 3-year-old seedlings on the heavier, disked soil. Disking undoubtedly improved soil characteristics, but that should not have caused a change in the relation of current to previous growth since it occurred before seedling establishment. The decomposition of the incorporated raw organic material, however, would tend to monopolize the available nitrogen and mineral nutrients for the first few years. As decomposition was completed, these substances would be released with the result observed here—greater current growth for a given amount of previous growth than in an undisked area.

It is apparent, therefore, that previous growth is the seedling characteristic that is most promising for field use, not only because it is more closely related to current growth but also because its relation to current growth, in the absence of disking, is not affected by differences among well-drained soils. The relation of current to previous growth for all except the 3-year-old seedlings in the heavier, disked soil, is as follows:

$$\text{Current growth} = 0.35 + 1.02\ (\text{previous growth})$$

[2]Pomeroy, K. B. and K. B. Trousdell. 1948. The importance of seed-bed preparation in loblolly pine management. Sth. Lumberm. 177 (2225): 143-144.

Since disking is not yet a general practice, this relation should be widely useful as an aid in judging the prospects of loblolly pine reproduction.

On the basis of the results reported here, little can be said about the effect of tipmoth attack on seedling growth. Under the conditions of this study, attack only in the preceding growing season did not deter seedling growth. Other work[3] has shown that tipmoth attack reduces height growth somewhat. Occasionally, particularly in plantations, attacks on some seedlings reach such an intensity that height growth is almost stopped.

Summary

Because information about future growth of loblolly seedlings is needed to evaluate the stocking of reproduction under even-aged management methods, the relation of growth to seedling characteristics and to gross soil differences, prescribed burning, seedling age, and Nantucket tipmoth attack was investigated. The height-diameter ratio, proportion of the main stem foliated, proportion of the main stem branched, stem form quotient, terminal bud length, needle length, number of branches, previous year's growth, and total height were studied. All of these except the branched proportion of the main stem were highly correlated with height growth in the succeeding year.

Seedlings of a given height and number of branches grew faster in a burned than in an unburned area. Seedlings attacked by the Nantucket tipmoth in only the preceding year grew faster than uninfested seedlings of the same height and number of branches.

The previous year's growth was deemed most promising for field use because its correlation with growth was very high, its relation to growth was linear and independent of seedling height, it was easily measured, and under normal conditions, it was not affected by gross soil differences, prescribed burning, or seedling age.

[3]Wenger, K. F. 1954. Release of loblolly pine reproduction. U. S. For. Serv. Stheast. For. Exp. Sta. Type. rept.

Description and Bionomics of a New Red Pine Scale, Matsucoccus Resinosae

BY

JAMES L. BEAN
PAUL A. GODWIN

BEFORE 1946 only one species of the coccid genus *Matsucoccus* was known to occur in the Northeast: *Matsucoccus gallicolus* Morr. The chief host plants of this species are pitch pine and scrub pine. It has not been found attacking red pine.

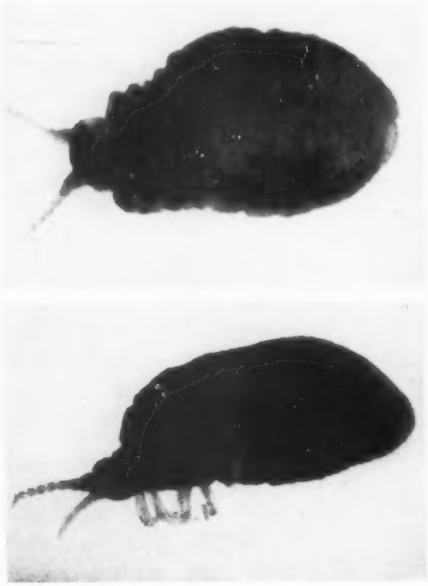

FIGURE 1. Matsucoccus resinosae, *adult female. Dorsal view (upper) and lateral view (lower). Photo from Conn. Agric. Exp. Sta.*

But in November 1946 a number of red pines (*Pinus resinosa* Ait.) in the vicinity of Hemlock Reservoir, Easton, Connecticut, were found to be heavily infested with a species of *Matsucoccus*. Preliminary studies have shown that on the basis of biology and host preference this newly found red pine scale is entirely different from all other known nearctic species of the genus. Taxonomically, the red pine scale is more difficult to define than the pitch pine species.

The genus *Matsucoccus* is not only of taxonomic interest, but it also contains species that are of considerable economic importance. The effects of these scales, which confine their attacks to the pines, is to injure the twigs and branches, weaken the crowns, and deform or kill the younger trees.

All known North American species of the genus *Matsucoccus* are given in a tabulation below with their hosts and their known distribution.

The authors are Entomologists at the Northeastern Forest Experiment Station, Forest Service, U. S. Dept. of Agriculture. They express great indebtedness to Dr. Harold Morrison, Taxonomist, Section of Insect Detection and Identification, Agric. Research Serv., U. S. Dept. of Agriculture, for assistance in preparing the technical description of *M. resinosae*.

Species of *Matsucoccus*	Hosts	Distribution
acalyptus Herbert	*Pinus edulis* *P. monophylla* *P. balfouriana* *P. aristata*	California, Arizona, New Mexico, Utah, Colorado, and Idaho
alabamae Morr.	*Pinus* sp.	Alabama
bisetosus Morr.	*P. ponderosa* *P. jeffreyi* *P. radiata*	California and Oregon
californicus Morr.	*P. ponderosa* *P. jeffreyi*	California and Arizona
degeneratus Morr.	*P. ponderosa*	Arizona
eduli Morr.	*P. edulis*	Arizona
fasciculensis Herbert	*P. ponderosa* *P. jeffreyi* *P. sabiniana*	California and Oregon
gallicolus Morr.	*P. rigida* *P. echinata* *P. ponderosa* *P. taeda* *P. virginiana* *P. glabra* *P. serotina*	New England west to Ohio and Missouri and south to Florida and Georgia
monophyllae McK.	*P. monophylla* *P. edulis*	California
paucicicatrices Morr.	*P. lambertiana* *P. monticola* *P. flexilis*	California, Oregon, Montana, and Wyoming
resinosae, n. sp.	*P. resinosa*	Connecticut and New York
secretus Morr.	*P. ponderosa*	California, Nevada, Arizona, New Mexico, and Colorado
subdegeneratus Morr.	*P. occidentalis* (*cubensis*)	Dominican Republic
vexillorum Morr.	*P. ponderosa*	California, Nevada, Arizona, New Mexico, and Colorado

Technical Descriptions

The genus *Matsucoccus* was set up by Cockerell (1909, p. 56) to accommodate a scale described by Kuwana (1905, p. 91; and 1907, p. 209) as *Xylococcus Matsumurae*. The chief characters of the original description, given in key form, are as follows:

Female without marsupium; broad posteriorly; not elongated, antennae 10-jointed, and very peculiar crab-like legs, the femur large; male without whorls of long hairs on the antennal joints; caudal brush long, arising from apical segment; rudimentary hind wing with very large hooks. (Japan).

Since the publication of the original description of the genotype, 14 new species, including the species described in this paper, have been described from North America, and the genus has been redescribed by Herbert (1921, p. 15). His definition of the genus follows.

Coccidae referable to the subfamily Margarodinae; i.e., adult female and first larva

with legs and antennae, and at least one intermediate stage without these appendages.

Adult female elongate, broader posteriorly, with 9-segmented antennae, the latter transversely striated, except 1st and 2d segments. Legs well developed, also transversely striated. Tarsus attached at apex of tibia and strongly curved outward; with spines on inner margin of tibia, two hair-like digitules on tarsus and two knobbed digitules on tarsal claws. Without marsupium or anal tube. Mouthparts sometimes present.

Intermediate larval stage without legs, antennae or anal tube, the only conspicuous characters being mouthparts and spiracles. First stage larva with legs and 6-segmented antennae. All three stages possessing two thoracic and seven abdominal pairs of spiracles.

The Division of Forest Insect Research,[1] Northeastern Forest Experiment Station, has for the past 3 years been conducting biological and seasonal-history studies of a new species of *Matsucoccus* occurring on *Pinus resinosa* Ait. These studies have been sufficient to call for a technical description of the scale and its complex developmental stages. The species is described below.

Matsucoccus resinosae, new species

This new species of *Matsucoccus* belongs to the superfamily COCCOIDAE, family Margarodinae, tribe Matsucoccini. A technical description of the various stages follows.

Adult female. Body strongly elongate-ovoid (Figs. 1 and 2), anterior apex almost angulate, characteristically widest behind the middle of the abdomen. Size is variable, one well-developed and probably average example measured 4.25 mm. long by 2.5 mm. wide. Derm is membranous, though densely stippled throughout with somewhat darker dots as in other species of the genus.

Antennae (Fig. 3) characteristic for the genus, with a pair of curved sensory setae on each of the four terminal segments and with a loose cluster (usually 5 to 6) of sensory pores on the second segment, all segments beyond the second having an imbricate-reticulate pattern distinctly developed on the distal portion of each segment, with this visible over most of the surface of the four terminal segments. Segmental lengths of an average antenna: I, 58μ; II, 87μ; III, 63μ; IV, 71μ; V, 71μ; VI, 63μ; VII, 59μ; VIII, 63μ; IX, 67μ.

Eye small, about 16μ in diameter in specimens examined, subhemispherical, in center of a flattened sclerotized cone with an irregularly circular diameter of 40 to 48μ.

Legs (Fig. 3) characteristic for genus, the parts showing the usual imbricate-reticulate pattern, length of these for an average posterior

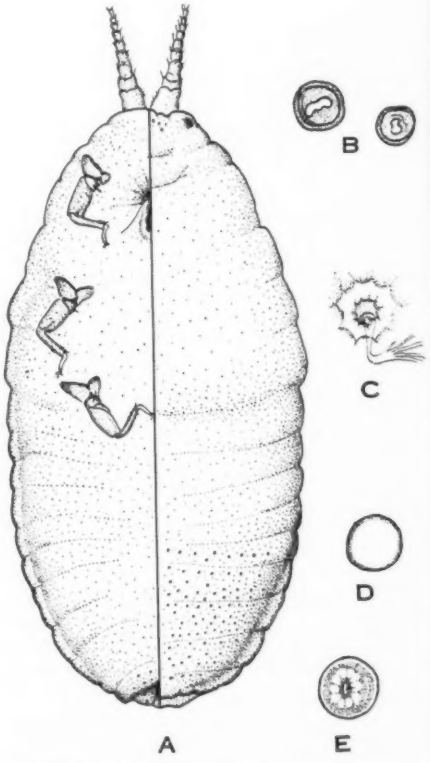

FIGURE 2. Matsucoccus resinosae, *Adult female.* A, *outline of body, ventral (left) and dorsal (right)*; B, *bilocular derm pores*; C, *abdominal spiracle*; D, *dorsal cicatrice*; E. *multilocular derm pore, surface view. (Drawing from mounted specimen.)*

[1]Formerly the Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine.

leg: trochanter, 126μ; femur, 320μ; tibia, 346μ; tarsus, 174μ; claw, 35μ; claw digitule, 47μ; a single slender seta on each trochanter up to 95μ long; claw digitules strongly enlarged and flattened apically as in other species, the swollen portion including about half the total length.

Beak is not developed, but is not completely suppressed. Characteristically it has sclerotic thickenings and folds at the point between the anterior coxae where it usually develops.

Spiracles are characteristic for the genus, weakly sclerotized, simple, no associated pores either internally or externally adjacent to opening; thoracic spiracles with an approximately globular atrium 28μ in diameter in one example, with small, usually irregular, external opening and an internal trumpet-shaped extension with swollen inner end, and extending from this a cluster of tracheae; abdominal spiracles in seven pairs, atrium obscure, perhaps collapsed in specimens examined, most obvious structure an internally gradually expanding tube with swollen end receiving numerous small tracheae; internal extension perhaps half the size of that of thoracic spiracle.

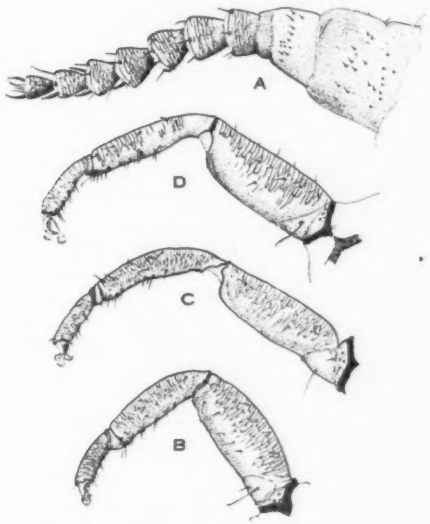

FIGURE 3. Antenna and legs of Matsucoccus resinosae *adult female.* A, *antenna*; B, *prothoracic leg*; C, *mesothoracic leg*; D, *methathoracic leg.*

Derm pores are characteristic for the genus, including the bilocular short-tubular ducts in rows or loose bands around the body, one of these to a segment, with a short incomplete row from each margin alternating with the complete bands at least on the abdomen; a cluster of similar pores, but each with an enclosing row of small loculi around pore opening; simple bitubulars not numerous, about 57 in the complete circle around the second abdominal segment (associated with first pair of spiracles), and about 71 in the third segment in one individual; apical, multilocular pores variable in number, 44 to 73 in specimens examined, simple bitubulars about the same size both dorsally and ventrally, sides about parallel with the inner end somewhat swollen, length about 7μ, greatest width (across both tubes) about 3.5μ; multiloculars with a surface diameter around 8 to 9μ, loculi somewhat obscured in material studied, apparently about 10 to 12 in a characteristic pore, bilocular center short, about 4.5μ.

Body setae are few; tiny, widely scattered, dorsal about 10.5μ long, ventral near margin the same, a few close to mid line on posterior abdominal segments considerably longer, 32 to 36μ or even up to 40μ, all stiff, tapering to acute tips. Dorsal cicatrices are of intermediate size, somewhat variable in diameter, recorded range 7 to 10.5μ, characteristically restricted to the posterior half of the abdomen, possibly arranged in five transverse bands but appearing so scattered in mounted specimens as to make this conclusion uncertain, recorded total numbers for individual specimens varying from 176 to 258, usually more than 200. Genital opening is situated at the bottom of a shallow vertical cleft at the posterior apex of the abdomen; usually it is obscured by dermal folds. *Intermediate female and male.* Probably characteristically stout elliptical in shape or tapering somewhat posteriorly, fully matured examples as much as 0.7 mm. long, derm somewhat sclerotized but not exhibiting any sort of recognizable pattern (Fig. 4). The original color is an amber-yellow, changing later to a grayish-yellow with darker margins. The legs and antennae are entirely wanting.

Spiracles at the bottoms of short tubes with tube length approximating diameter at bottom; thoracic and anterior abdominal spiracles approximate in size, the remaining six abdominal gradually reduced in size in sequence; spiracular pore plates not strongly pedicillate, about

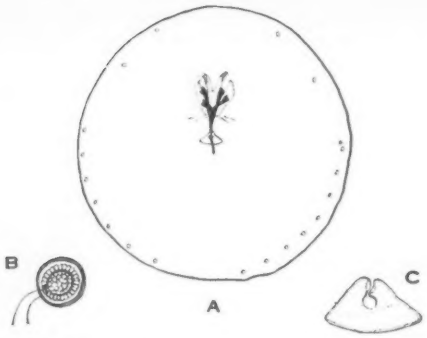

FIGURE 4. Intermediate female of Matsucoccus resinosae. A, *outline of body, ventral*; B, *right thoracic spiracle, with disk pore plate*; C, *beak.*

50 to 52 irregular pores, in each spiracular pore plate the largest around the margin, with about 33 in the anterior abdominal and 14 to 17 in the apical, in specimens examined; trachea entering the thoracic spiracle opposite the posterior median (inner) curve of the pore plate in contrast to the condition reported for some other species described from this country, but in the usual position along the posterior curve, in the abdominal spiracles; pore plate diameter of anterior spiracles in one individual 32 to 35μ, anterior abdominal spiracle 24 to 26μ, apical spiracle 12 to14μ; mature individuals and cast skins showing a dark ring or band around each spiracle opening.

Derm at molting breaks irregularly at the posterior end of the body for the emergence of the adult. Male form of this stage is similar to that of female except smaller.

First-stage larva. Characteristic for the genus (Fig. 5). One individual, after enlargement but before feeding, 410μ long by 197μ wide, long ovoid, tapering more strongly anteriorly. Derm membranous. Antennae quite close together at base, interspace about one -third width of a basal segment: I, very stout, 24μ wide by 14μ greatest length; II, 15μ long by 12μ wide; III, 4μ long; IV, 16μ long; V, 8μ long; VI, 28μ long, apical sensory spines 12 and 13μ long; legs and beak characteristic. Eyes fairly prominent, approximately hemispherically protruding, basal diameter about 12μ; thoracic spiracles minute, inconspicuous, the 7 abdominal pairs much more evident, each with the trachea entering the center of an apparently poriferous disk set at the bottom of a faintly sclerotized, invaginated dermal cup, this cup barely evident with the anterior spiracle but gradually deeper with each succeeding posterior spiracle, with the apical invaginated almost the diameter of the plate; anal lobe seta about 160μ long.

During the growing period a gradual change in shape and size takes place. With the increase in body length a waxy secretion forms along the posterior margin, eventually covering the abdomen. This is followed by a gradual swelling of the cephalo-thoracic area, giving the scale a pear shape. The actual shape depends on the space into which the larva crawls.

The egg. The egg is elongate-ovoid with both ends broadly rounded; color amber-yellow, with a smooth and shining surface, approximately 0.20 mm. long by 0.16 mm. wide; enclosed in a white, waxy secretion. Several hundred eggs are enclosed in one egg mass. During oviposition the female covers each egg,

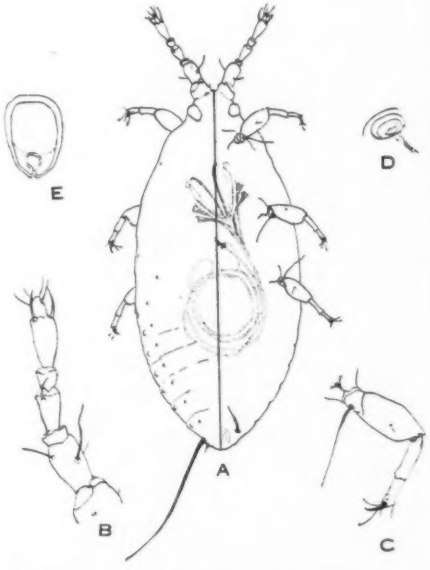

FIGURE 5. First-stage larva of Matsucoccus resinosae. A, *outline of body, dorsal (left) and ventral (right.)* B, *antenna*; C, *leg*; D, *thoracic spiracle*; E, *beak.*

as it is laid, with a loose coating of white, waxy filament. Then the eggs are enclosed in a much larger, loosely woven ovisac. Counts made of field-collected ovisacs gave an average of 300.5 eggs per ovisac with a maximum of 413 and a minimum of 118.

Preadult male. The preadult male is similar to the adult female but somewhat smaller (1.0 to 2.5 mm. long). Antennae and legs are alike in all respects. Derm varies in color from a light to reddish brown with the light yellow wing pads plainly visible beneath the body integument. Pupates in a loose, fluffy, spindle-shaped, waxy cocoon.

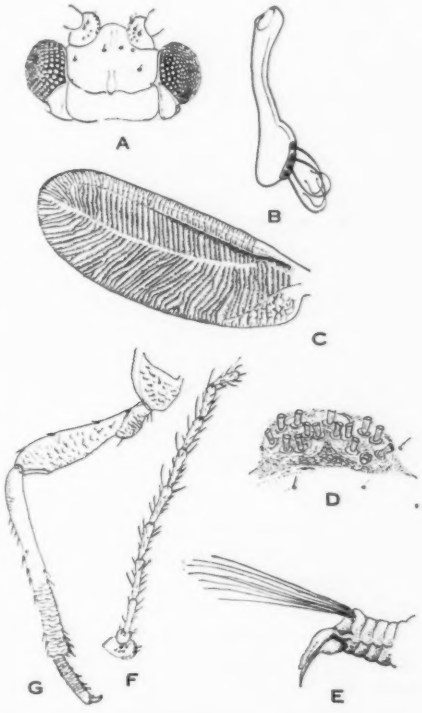

FIGURE 6. Adult male of Matsucoccus resinosae. A, *head, venter*; B, *halter*; C, *wing, showing shape and venation*; D, *caudal brush at end of abdomen*; E, *abdomen, lateral view showing waxy filaments projecting from caudal brush*; F, *antenna*; G, *methathoracic leg.*

Adult male. The adult male (Fig. 6) is practically identical in appearance with this stage of the genotype *M. matsumurae* (Kw.). No critical studies are yet available to establish bases for segregation of species in this stage. The adult male is 2-winged, midge-like in appearance, about 1.0 mm. long, legs and antennae long and slender, transversely striated, the latter 9-segmented. It is easily identified by the peculiar wing venation and the prominent caudal brush at the end of the abdomen. Brush is composed of several long, white, waxy filaments projecting posteriorly.

This insect has been described from a number of individuals of the different stages collected in Connecticut and New York. The female holotype has been selected from specimens collected on *Pinus resinosa* at Easton, Conn., June 2, 1948, by George H. Plumb. Paratypes of the different stages, all from the same host, and including additional adult females, come from Easton, collected by Plumb, Nov. 29, 1946; from Syoset, Long Island, N. Y., collected by Mrs. B. Moore, Dec. 9, 1948; from Fairfield, Conn., collected by S. W. Bromley, Nov. 16, 1950; from New Rochelle, N. Y., collected Sept. 1952, and from Bridgeport, Conn., collected by J. L. Bean, Oct. 15, 1952.

As with most of the species of this genus, there are few, if any, positive morphological characters that can be cited as firm guides to recognition; and as of now, the host and environmental associations that have been established for the species in the area in which it is known to occur have greater recognition significance than do its morphological characteristics.

The adult female seems similar to the true *Matsucoccus matsumurae* (Kw.) from Japan in many structural details, including the tendency of the dorsal cicatrices to spread out over the surface of the abdomen so that it becomes difficult to recognize sharply limited bands and clusters. But the trachea in the thoracic spiracle of the intermediate stage enters the spiracle opposite the posterio-median curve of the pore plate, resembling the condition in *Matsucoccus pini* Green, as recently described by Boratynski (1952, pp. 285-326), while the point of entry in this stage of *M. matsumurae* is on the anterior curve of the plate, as with various North American species.

The types are in the U. S. National Collection of Coccidae.

Geographical Distribution

Matsucoccus resinosae was first reported in 1946 by George H. Plumb. The insect was seriously damaging 30-year-old red pines at the southeastern end of Hemlock Reservoir at Easton, Conn. By 1950 the scale had spread to the Easton Lake Reservoir, approximately 4 miles to the northeast. Spread is apparently effected by the wind, for studies made in 1952 showed that first-stage larvae were definitely airborne for at least ¼ mile. In 1953 a survey conducted by the State of Connecticut[2] showed that the infestation had spread over an area of at least 60 square miles (Fig. 7).

The scale was reported from New York in 1950. An intensive survey conducted by the State of New York in 1953[2] showed that an area of approximately 40 square miles was infested on Long Island, and scattered spot infestations occurred along the Hutchinson River Parkway and in Yonkers, Scarsdale, and Tuckahoe in Westchester County (Fig. 7).

The area in which *M. resinosae* now occurs is south of the natural range of red pine. The infested red pines are found only in plantations, in nurseries, or as ornamentals. A cooperative survey of red pine stands in northern New York and New England was undertaken in 1953 by State and Federal personnel to determine if the scale occurred in natural stands of red pine. Both natural and planted red pines were sampled, with special emphasis given to natural stands. No evidence of *M. resinosae* was found.

To date no evidence has been obtained to indicate the origin of this scale. However, the rapid spread of *M. resinosae* in Connecticut since 1946, and the heavy mortality of red pine as a result of its attack, would suggest the scale may be an introduction.

[2]Special report on a cooperative survey for the Matsucoccus scale of red pine in the northeast—1953. U. S. Dept. Agric. Div. For. Insect Invest. 7 pp., illus. 1954. New Haven, Conn.

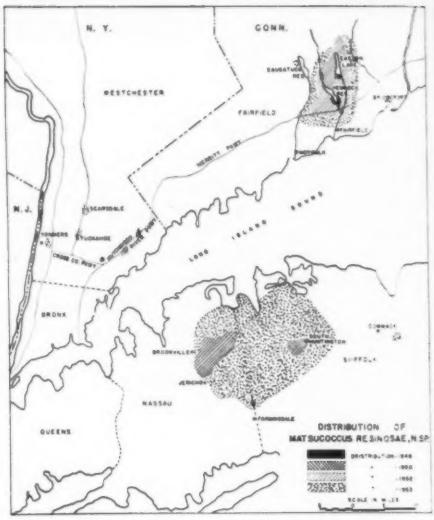

FIGURE 7. The known distribution of Matsucoccus resinosae.

Cooperative studies are now being conducted with the Boyce Thompson Institute in Yonkers, N. Y., to determine scale survival at different low temperatures. It is hoped that this study will determine if a thermal barrier exists that may prevent northward spread of this insect into natural red pine stands.

Host Relationship

Matsucoccus resinosae is apparently host specific. Laboratory experiments carried out in 1952 and 1953 to establish the scale on other species of pines (jack, pitch, scotch, white, Austrian, and mugho) were unsuccessful. In the field, scale-infested red pines were found growing intermixed with these same species of pines, but only the red pine was infested. In nearly all cases the red pine eventually died as a result of feeding by the scale.

Studies of host relationship will be undertaken this year, in cooperation with the Boyce Thompson Institute, using exotic pines as possible hosts of the scale.

Effect on Host

The first visible foliar indication of feeding by *M. resinosae* is a slight yellowing and shortening of the new growth. However, this does not occur until the tree has become rather heavily infested. The discolored and shortened growth may not appear immediately over the entire crown, but only on an occasional branch.

As the scale population increases and feeding becomes more severe, the color of the foliage changes from a normal green color to light green, then to light yellow, and finally to a brick-red. This occurs first on individual branches, then over the entire crown. This color change may occur rapidly; some pines with only a single off-color branch in the spring were entirely brick-red by late fall.

The bark on branches and boles that are heavily infested with the scale has a swollen and cracked appearance, and areas of necrotic tissue can be found beneath each feeding scale.

Economic Importance

The infestation of *M. resinosae* has now reached serious outbreak proportions, and the insect has become one of the most serious pests of red pine. The present infestation, although restricted to definite localities, constitutes a very serious threat to thousands of acres of planted as well as natural red pine in the Eastern States. The State of New York alone has planted more than 98 million red pines on approximately 135,000 acres in addition to another 25,000 acres planted on private lands.

The State of Connecticut has approximately 20,000 acres of red pine planted, mainly on watershed property. In New Jersey there are approximately 6,000 acres of planted red pine. The plantation figures for red pine in the other Eastern States are not available; however, they involve several thousand acres.

The volume of natural red pine throughout the region is very large and is of considerable economic importance. For example, there are about 250,000 cords of red pine in the State of New Hampshire alone.

Habits and Seasonal History[3]

Habits

The newly hatched larva of *M. resinosae* is very active and may crawl a considerable distance before it settles down to feed. However, as soon as the young crawler locates a suitable hiding place, either under a loose bark scale or in a crack or crevice, it inserts its long stylet into the bark, commences to feed, and remains quiescent until full-grown. Once the stylet has been inserted, the scale cannot be disturbed or it will die.

Generally the young crawlers are gregarious and may be found in large numbers just under the edge of a loose bark scale (Fig. 8). As many as 53 individual first-stage larvae have been found under one bark scale.

The duration of this stage varies considerably, ranging from 45 to 50 days for the summer generation, and 235 to 260 days for the fall or overwintering generation.

At ecdysis the skin of the first-stage larva splits anteriorly and longitudinally along a mid-dorsal and -ventral line. The antennae and three legs appear on one side of the split and the remaining three legs on the other. The cast skin gradually slips sideways and backwards, eventually encircling the posterior half of the body.

The body of the intermediate stage, following ecdysis, is stoutly ovoid, more or less distorted from its cramped hiding place. The derm at first is soft and membraneous, later becoming very hard, thin, and homogeneous, more or less strongly sclerotized, especially along the margins. The rapid growth of the scale during this stage indicates a considerable amount of feeding.

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[3]The authors thank the Bridgeport Hydraulic Company of Bridgeport, Conn., for their splendid cooperation in the study of the habits and seasonal history of the red pine scale, and the active part they played in the insecticide studies carried out in 1954.

FIGURE 8. Matsucoccus resinosae *first-stage larvae on twig of infested red pine. The bark scale has been removed to expose the insects. Photo from Conn. Agric. Exp. Sta.*

FIGURE 9. Masses of male cocoons on lower side of branch axil. Photo from Conn. Agric. Exp. Sta.

When fully developed, this stage of *M. resinosae* is nearly globular in shape, with hard leathery skin, blackish in color. The expanded size of the scale has forced it partly out of the crevice in which it was hiding, and gives it the appearance of a glob of black pitch. The mouth parts, the only means of attachment to the host plant, become very brittle and break at the least pressure.

It is not known for certain just when feeding ceases during this stage. A number of fully developed individuals were removed from twigs and kept in small vials; these invariably failed to molt into adults. Similar individuals not removed from the same twigs molted 2 to 4 days later. This would indicate that growth continues almost up to the time the scale molts.

With this second and final molt the adult female, or preadult male, emerges from the cast skin by backing out through the opening, helping itself with haphazard movements of its legs.

The male form emerging at this time is not the true adult, although it is almost identical to the true adult female. The male form at this stage is called the preadult; it must go through another transitional period before becoming the true adult.

Almost immediately after emergence, the preadult male spins a loose, fluffy, spindle-shaped cocoon of coarse, waxy threads. Within this cocoon the transformation to the winged adult occurs. The preadult males are gregarious and gather in large numbers on the undersides of branches, especially at branch axils, to spin their cocoons (Fig. 9). On heavily infested trees these masses of cocoons are very conspicuous and resemble small fluffs of cotton.

The reddish-brown adult female is very active, although awkward of movement. She may crawl a considerable distance over the bark, continually investigating cracks and crevices until she finds a suitable place for laying eggs. This may be any crack or crevice in the bark or under a loose bark scale. The axils of branches provide the best shelters and many ovipositing females may be found there. The duration of the active life is not known. However, in small vials females have wandered around for 3 days before laying their first egg.

Once the female finds a suitable place for laying her eggs, she wedges her head and thorax into the deepest part of the crevice and firmly fixes herself with her claws. In a short time waxy threads are exuded from the abdominal wax pores, forming a loosely wooven ovisac, and oviposition begins. In this position the female will lay her quota of eggs and then die.

Seasonal History

This is the second recorded species of the genus *Matsucoccus* that has two generations a year. *Matsucoccus pini*, a European species found only on *Pinus sylvestris* and limited in its distribution to southern England, is the only other known bivoltine *Matsucoccus* species. Morphologically, *M. pini* resembles *M. resinosae* very closely; but it differs, in addition to distribution, in its host preference and in being parthenogenetic.

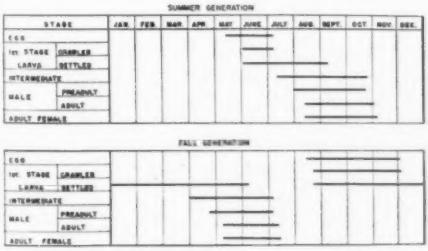

FIGURE 10. The seasonal life cycle for summer and fall generations of Matsucoccus resinosae.

In southern Connecticut and New York, where *M. resinosae* now occurs, there are two generations a year: a summer generation, with the first eggs laid in May and adults emerging in early August; and a fall generation, with eggs laid in late August or early September and adults emerging the following spring (Fig. 10). All evidence collected to date indicates that the fall generation overwinters as a partly grown first-stage larva. In the spring, feeding is resumed and the first molt occurs. The resulting legless intermediate stage develops rapidly and by the third week of April preadult males appear. They immediately enclose themselves in silken cocoons and in 10 to 14 days transform into the true adult.

The emergence of the true adult males coincides with the emergence of the adult females. After copulation the females seek suitable shelters and lay the eggs that will produce the summer generation. Under laboratory conditions egg-laying varied from 2 to 4 days. Adults from the overwintering generation may continue to emerge until the first week of July.

Newly hatched larvae have been found in the field 15 days after the eggs were observed. This corresponds very closely to the 15 to 20 days required to hatch eggs under laboratory conditions. The active life of the young crawlers is very short. Settled individuals may be found almost simultaneously with the appearance of the first crawler. Feeding first-stage larvae may be found throughout the year, and in August and September and in early June there is an overlapping of both summer and fall generations.

In approximately 45 days the first-stage larvae reach their full growth and the first molt occurs. The resulting intermediate stage makes its first appearance about the middle of July. During this stage the scale continues to feed, and it increases rapidly in size. When full-grown, the intermediate form may be twice the size of the first-stage larva just prior to molting. It is not known if feeding continues right up to the emer-

gence of the adults or if there is a short resting period in between. However, by the first of August preadult males of the summer generation were first observed in the field. These preadults also transform into the true adult males and emerge around the middle of August—at the time the adult females are emerging. Adults of the summer generation may be found in the field until the last of October.

The eggs now laid hatch around the last of August and the crawlers of the fall generation appear. Newly hatched crawlers of this generation may be found as late as the first of December, but it is doubtful if these late arrivals are able to survive the winter.

On the basis of these field observations the life cycle of *M. resinosae* requires approximately 84 days for the summer generation and 259 days for the fall generation.

Control

Chemical Control

During the past 4 years emphasis has been placed on the testing of various insecticides to control this pest (Table 1). The insecticides were applied to small scale-infested red pine seedlings using a 2-gallon knapsack sprayer to apply the spray. Three of these insecticides (Systox, a systemic poison; ethylene dibromide; and a 2-percent oil emulsion) showed some promise of effecting control. These insecticides were field-tested in 1954, using a two by three factorial experiment involving two methods (hydraulic sprayer and mist blower) applied four times (April 22, May 19, June 8, and June 27) with replicated plots.

The analysis of the over-all average degree of control obtained from the various treatment combinations may be summarized as follows:

TABLE 1. Results of insecticide tests.

Insecticide tested	Date applied	Results
Endrin	Apr. 28, May 5, May 19	No evidence of control. Many living scales found at end of season.
Compound #711	Apr. 28, May 5, May 19	Same as for Endrin
Aldrin	Apr. 28, May 5, May 19	Same as for Endrin
Heptachlor	Apr. 28, May 5	Same as for Endrin
2-percent oil emulsion	May 5, May 19, July 22, Aug. 5	No living scales found on sprayed trees by end of August. Check trees showed increase in population.
Do.	Aug. 20, Sept. 9	Some reduction of summer brood, but resulting fall brood not reduced.
Systox	May 5, May 19, July 22, Aug. 5	Same as for 2-percent oil.
Do.	Aug. 20, Sept. 9	Some living scales of the fall brood found on sprayed trees in early October, but by December 1 these were all dead. Checks showed an increase in population.
Ovatran + Aramite	May 19, June 9	No control noted.
Malathion	July 22, Aug. 20	Some control noted, but uncertain—sprayed trees had light infestation.
Ethylene dibromide	Aug. 20, Sept. 9	No living scale found on sprayed trees in late October. Apparently good control of first-stage larvae obtained.
Orthodichlorobenzene	Aug. 20, Sept. 9	Some reduction in population noted, but insufficient to effect control.
Lindane	Aug. 20	No evidence of control noted.

1. The May 19 and June 8 application averaged a significantly higher degree of control than either the April 22 or June 27 application.
2. There was a small but significant difference between the three insecticides; Systox averaged highest and ethylene dibromide next in effectiveness.
3. The mist blower, on the average, proved more effective than the hydraulic sprayer.
4. Systox applied by the mist blower averaged the highest effectiveness, with the 2-percent oil emulsion applied by the mist blower and Systox applied by hydraulic sprayer next.
5. The single most effective treatment was the 2-percent oil emulsion applied by the mist blower on June 8, ethylene dibromide and the 2-percent oil emulsion applied by hydraulic sprayer on May 19 were nearly as effective.

The control effected by these single applications was considered unsatisfactory for the purposes of practical control. Further tests are needed, using double applications against the feeding stages (May 19 and June 8) with these same insecticides or with others of equal effectiveness.

Natural Control

Some observations have been made on the natural enemies of *M. resinosae*. A number of predators were collected and reared, but so far no conclusive evidence of parasitism has been found.

One of the most abundant predators reared—and apparently the most beneficial—was a small hemipteron (*Xanotrachelliella inimica* D. & H.).[4] This anthocorid bug was reared on all stages of the scale, but it seemed to prefer the eggs and first-stage larvae. It was very abundant on all scale-infested trees. Adults were collected as late as the last of October.

Another predator, a small coccinellid (*Cleis picta* (Rand.)) appeared to be the next most abundant. Larvae of this beetle were also successfully reared on all stages of the scale. Larvae of a small hemerobiid (*Hemerobius stigmatus* Fitch) and a chrysopid (*Chrysopa* sp. near carnea group) were observed feeding on the eggs and first-stage larvae of *M. resinosae*.

A number of small orange-colored dipterous larvae (*Itonodidini* group *Trifila*, genus and species unknown) were found feeding on eggs within the ovisac of this scale. These larvae were able to consume all of the eggs in one or more ovisacs before they pupated. A small black ant (*Crematogaster cerasi* (Fitch)) was common on scale-infested trees, probably associated with an aphid (*Pineus* sp. (?)) found in abundance on these pines. On several occasions they were observed attacking the crawlers and adult females of the scale.

Plumb[5] reports certain species of spiders as being predacious on the scale. These were collected from red pine on October 13, 1950, and were identified by Dr. B. J. Kaston. They are: *Pityohyphantes phrygianus* Koch, *Theridion unimaculatum* Emerton, *Uloborus americanus* Walckenaer, *Metaphidippus proteruns* Walckenaer.

Spiders of the genus *Theridion* were especially common, and many adult *Matsucoccus* females were observed in their webs.

Mites of the genus *Anystis* were observed by Plumb (1950, p. 4) feeding on the different stages of *M. resinosae*. They occurred in large numbers on scale-infested material.

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[4]Species was determined by taxonomists in the Section of Insect Detection and Identification, Entomology Research Branch, Agric. Res. Serv., U. S. Dept. of Agriculture.

[5]Correspondence, January 13, 1955.

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